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N:o 40

ON THE PETROLOGY ON THE ORIJÄRVI REGION IN SOUTHWESTERN FINLAND

BY

PENTTI ESKOLA

WITH 2 MAPS, 6 PLATES AND 55 FIGURES

HELSINGFORS
APRIL 1914


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GEM·CUTTING
GEMSTONES·OF·NORTH·AMERICA·PROSPECTING·FOR·GEM
STONES·AND
MINERALS
MINERALOGY·EMERALD·AND·OTHER·BERYLS·CATALOG
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Contents.

History of the geological exploration of the Orijärvi region.

More than 200 years ago the area, which forms the subject of this treatise, was known as an ore-bearing district. Thus the iron ore of Malmberg in the parish of Kisko was detected in 1670, and at the same time the working of a silver mine at Aijala, Kisko, was begun. About the middle of the subsequent century, in 1757, copper ore was found at Orijärvi. Ever since that time prospecting work has been carried on in this region, and innumerable pits and small quarries, many of which in the writings of H. J. Holmberg (1857 and 1858) are said to be old and of unknown date, testify to the activity of former miners and prospectors. This activity reached its maximum in the earlier decades of the 19:th century, as a result of the endeavours of Nils Nordenskiöld, the renowned mineralogist, who was at that time Director of Mines. At this time geognostic researches were undertaken in connection with the prospecting works. In the southwestern portion of Finland Fr. Tengström, Gustaf Albrecht, A. F. Thoreld, E. J. Westling, Lars Igelström and others were at work. The last-mentioned also made a geological map of the parish of Kisko. [1] At this time the first researches dealing with the minerals of Finland were made by Nils Nordenskiöld and somewhat later by Adolf Erik Nordenskiöld, localities in southwestern Finland providing these workers with the bulk of their material. But although the Orijärvi region was then one of the best known in Finland, observations were as yet too few and heterogeneous to allow of any general view of its geology. The »geognostical» information accessible in the middle of the century, was collected and published by H. J. Holmberg (10 and 11).

In the sixties F. J. Wiik began to work at the geology of southern Finland; he has the merit of being the first to describe this country from the geological point of view. Wiik, however, paid no special

[1] Kept at the Archives of Bergstyrelsen, Helsingfors.

attention to the geology of the Orijärvi region, and only described the minerals which were found in the mine.

In 1865 regular geological surveying was started in Finland. During this and the subsequent year the southern part of the area represented on map I, accompanying this treatise, was explored under the direction of the »bergmaster» E. H. Furuhjelm, and thereafter the work was continued under the direction of K. Ad. Moberg. Sheet I (Kimito) of the geological map, with an explanatory text (18), including the western and larger part of the area in our map I, was published in 1878, and in the year 1879 sheet II Lohja (19), including the Orijärvi ore field, appeared. These sheets of the geological map are still very serviceable in so far as they represent the quaternary deposits, but the view they give of the Archaean rocks is too much generalized, the use of the term gneiss being far too comprehensive. All quartz-feldspar-rocks which show parallel structure were designated as gneiss whatever their texture in other respects might be. Thus, such dissimilar rocks as the fine-grained leptites and the medium-grained, feebly foliated gneiss-granites (our oligoclase-granites) and even coarse-grained and porphyritic microcline-granites, showing a parallel flow-structure, have been designated with one and the same colour.

In 1889 and 1890 the Orijärvi mining field and its environs were explored both from the technical and the geological point of view by the mining engineer A. F. Tigerstedt, now President of the Board of Industry. The maps and field observations of Mr. Tigerstedt, which have never been published in full, were made with conspicuous skill and care. A summary of his unpublished reports (25 and 26) may be here included.

Tigerstedt's map comprises an almost square area of about 40 km^2, the centre of which lies in the most northern point of the shore-line of Lake Määrijärvi. Generally speaking, the revision of this area by the present writer has shown no reason for essential changes. Thus Tigerstedt's map affords, in its principal features, almost the same reading of the area as does our map II, the only important difference being that the latter shows only one granite whilst I have separated the granites into a younger and an older group. In the explanatory text the area of crystalline schists was divided by Tigerstedt into two principal parts: (1) The limestone- and ore-bearing series and (2) the leptite series without limestone. To (1) belong the areas situated at each side of the central granite batholith, bounded in the North by the long sill of amphibolite (called diorite by Tigerstedt) which occurrs immediately to the North of Lake Orijärvi. As the rocks dip to the North on the northern side of the granite and to the South on the southern side, the layers are believed to form an anticline tilted up by the intrusion of the granite. At the sides, however, there is the complication of repeated folding. Tigerstedt leaves it undecided, whether the wide areas of leptites in the North, where the tectonics seem to be more simple, belong to a single thick series of strata, being newer than the limestone- and ore-bearing series, or whether the apparent thickness of the strata has been multipled by faulting. To illustrate his explanation of the tectonics, two of the many sections constructed by him may be given here, (fig. 1). Among the leptites (called granulites) several subdivisions have been separated according to their texture or important accessories. Such are the gneissose granulites (occurring in the neighbourhood of the granite and believed to be altered by a contact-metamorphic influence caused by the latter), the hornblende-granulites, the mica-schistous granulites etc. As varieties worthy of special note, Tigerstedt mentions the actinolite- and cordierite-bearing granulites (really anthophyllite-bearing) which are already known to be the bearers of sulphidic ores *par préférence*, and the mica-schists or mica-gneisses which occur in the vicinity of the Iilijärvi mine (really andalusite-bearing rocks). — The granulites are believed to be metamorphosed sediments, partly derived from tuffitic material.

All dark-coloured rocks (except the skarn) are termed by him diorites, and several groups of them are separated, according to their texture or some difference in their supposed origin. Some are believed to have been formed originally as lava-beds, others as agglomerates; many occurrences are supposed to consist of sills, and finally, in the southwestern portion of the district covered by the map, there is an area which he regarded as truly abyssal rocks (our diorites and gabbros). Their abyssal nature is proved by their massive and comparatively coarse-grained texture, which is contrasted with the fine grain and porphyritic or amygdaloidal texture which implies an effusive origin for other »diorites». Nonhomogeneity and a fragmental structure characterize the agglomerates. The intrusive nature of the bodies explained as sills is recognized by the fact that they sometimes cut obliquely across the intruded layers of granulite.

The »deep-seated diorite» of Tigerstedt passes by gradual transition into the granite. The possibility of assimilation by the granite is mentioned, but he regards it as being more probable that there is no essential difference in the their age and that the magma had already differentiated before the consolidation of the rocks.

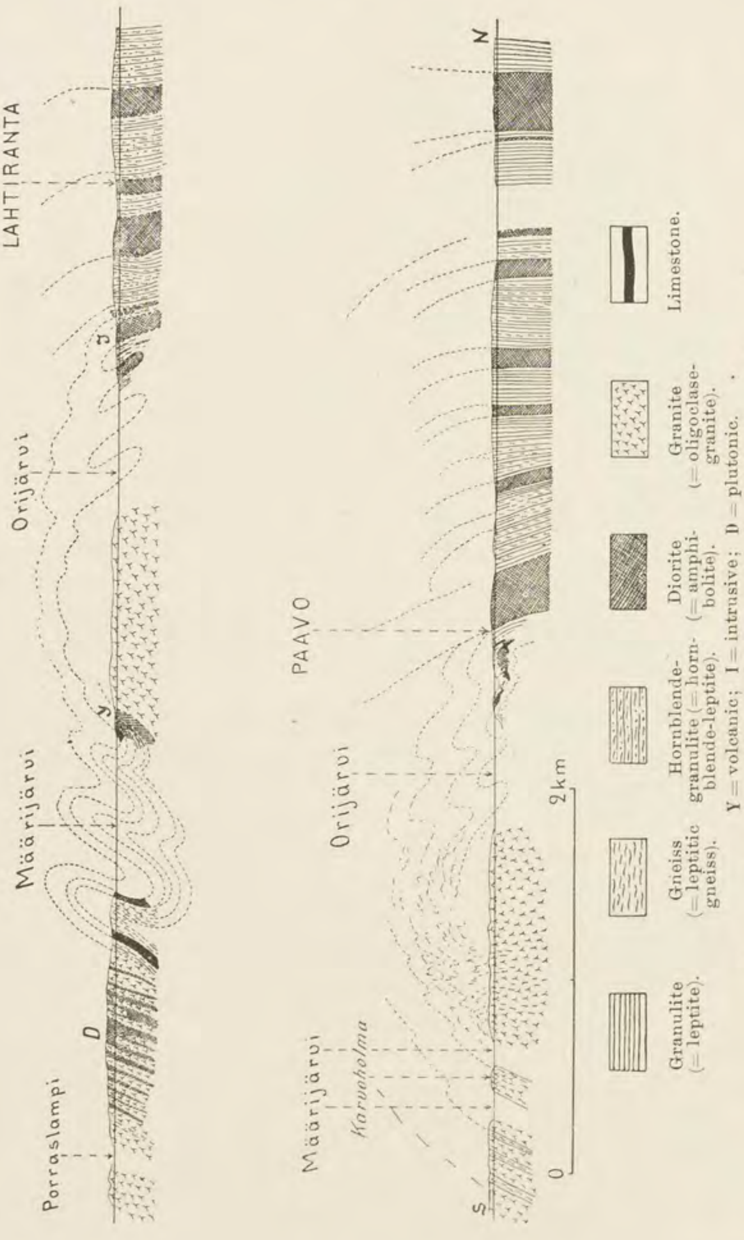

Fig. 1. Two sections across the Orijärvi field. After Tigerstedt.

Tigerstedt's memoir contains many important observations, concerning the granite: The rock is recognized as a metamorphosed granite, massive in the western part of the area, but distinctly foliated in the East. The contact-metamorphism, i e. the gneissification of the leptites by enlargement of their grains, is said to be more pronounced in the eastern portion, and here the rock also contains numerous fragments of the adjacent rocks, which is not so much the case in the West, where, on the other hand, the granite grades into a contact-modification with porphyritic quartz. Tigerstedt concludes, that in the latter we have a contact boundary formed near the earth's surface, but that towards the East the rockmasses which at the time of intrusion were at deeper levels within the earth's crust are now exposed.

The sequence of events, as interpreted by Tigerstedt, can be summarized as follows:

1) Deposition of sedimentary beds, now appearing in the form of leptites and limestone, and contemporary eruptions of effusive and intrusive rocks (»diorites»).

2) Orogenetic movements, folding of the strata to form an anticline, whereby the granitic magma is intruded to fill the centre of the fold. Metamorphism of the overlying rocks and of the granite itself, the folding continuing during and after the solidification of the granitic mass.

3) Denudation.

Special attention is laid by Tigerstedt on the occurrence of the ores. The sulphide ores of the Orijärvi mine are situated at the southern contact-wall of the long »diorite» sill. They are embedded partly in a »soft rock», composed chiefly of chlorite, talc and tremolite, which follows the boundary of the »diorite wall», also termed »great sköl» (stora skölen), partly in a »hard quartzose rock» (hårdt kvartsigt berg), at some distance from the diorite hanging wall. Concerning the origin of the ores, Tigerstedt believes that they are younger than their country-rock and have been carried in solution from greater depths in connection with the eruption of the »diorite», a view which had formerly been expressed by F. J. Wiik (17 page 87). The magnetitic iron ores are interpreted by Tigerstedt as layers of a true sedimentary rock.

Since Tigerstedt's survey the geological exploration of southwestern Finland has been carried forward by J. J. Sederholm. Though the district now under consideration has not been directly the subject of this geologist's investigations, many of his conclusions are here applicable. Thus in the Orijärvi region the statement, that in large tracts of southern Finland there are two persistent types of granites of very different ages, holds good (**29**). The older of these is usually gneissoid and rather »basic», the newer a massive and »acid» gra-granite. Sederholm's investigations on the refusion or anatexis of rocks (**33**), mostly carried out in the Hangö archipelago, not far from the leptite area, also find application in several parts of the area of our map I.

A discovery of zinc blende on the landed property of Brödtorp, about 10 km south of Orijärvi, in 1904, gave cause for renewed geological investigations. In the same year the mining engineer O. Trüstedt examined the occurrence of Brödtorp, or Nyckeln, as the mine was then called. Later on Mr Trüstedt carried on economic-geological explorations at the Orijärvi mine (**36**) and went on to theoretical researches upon the genesis of the ores. A summary of his conclusions, with a sketch-map made according to Tigerstedt's map, with a few corrections, is published in Beck's »Erzlagerstättenlehre« (**37**). Trüstedt agrees with the opinion of Tigerstedt as to the epigenetic nature of the ores at Orijärvi, but he does not believe that they have been brought up by the »diorite». Instead he regards it as probable that the ores are connected genetically with the newest rock in this region, the »post-Bothnian» granite, which occurs as a large mass about 4 km to the East of the Orijärvi mine.

Recently the geology of the Orijärvi region has been dealt with by P. P. Sustschinsky (**41**). The volume by this author contains a treatment of the contact-phenomena between the limestones and the deep-seated rocks in southwestern Finland, and includes a mineralogical and petrographical description of numerous limestone quarries in the area represented in our map I, as well as a description of the ore-field of Orijärvi and other old mines in its neighbourhood. Sustschinsky's researches deal mainly with the results of a microscopical and chemical examination of specimens collected by him during several excursions, and his field observations do not seem to have been very extensive. From his observations Sustschinsky was led to the conclusion that the ores of Orijärvi are of contact-metamorphic origin, due to the post-volcanic action of the adjacent granite, which is supposed to be of a post-Bothnian age. As we shall have repeated opportunity of referring to the work of Sustschinsky, a summary of its contents is not necessary here.

In the year 1907 the state geologist Dr. B. Frosterus surveyed in detail a limestone- and ore-bearing area near the railway-station of Skogböle in the parish of Tenala. The many interesting features observed by him during that summer caused the Geological Commission to plan a renewed exploration of the district between Orijärvi and Skogböle, and in the summer of 1908 the present writer was sent to survey the Orijärvi Region. During that summer nearly all the portion of the parish of Kisko represented on sheet 2, Lohja, of the geological map of Finland, was mapped. In the summers of 1909—1912 the work has been continued westward, and the whole area of sheet 1, Kimito, was thus revised by the writer. In the summer of 1913, a period of two weeks was given to revision of the work done in the vicinity of Orijärvi.

Of the area represented in map I, the district between the railway stations of Skogböle and Skuru was mapped out by Dr. B. Frosterus, the other parts being surveyed by the present writer. In the summers of 1912 and 1913 he was, during two months, assisted in this work by Mr. A. Laitakari. — In the course of surveying, topographical maps in the scale 1 : 20,000 (5 cm to 1 km) were used.

The purpose of the present work is to give an account of the petrology of a series of Archaean metamorphic rocks. From the area mapped out, the vicinity of Orijärvi has been chosen, and I shall endeavour to give the petrographic characteristics of all important types there found. The peculiar anthophyllite- and cordierite-bearing rocks will be described in somewhat greater detail than other rocks. Many groups of rocks not here treated in detail are being reserved for future publications. I refer especially to such as the pegmatites and the limestones.

The laboratory work for the present treatise has been done at the Mineralogical and Geological Institute of the University of Helsingfors, for the most part during the winters of 1912 and 1913.

Prof. W. Ramsay, the Director of the Institute, has kindly allowed me to freely use the chemical laboratory, the instruments and the collections of the Institute and, moreover, promoted my work with many critical suggestions. For all his kindness and assistance I wish to proffer to him my sincere thanks. To Dr. L. H. Borgström I am also very much obliged for his readiness to help me with valuable advice.

Prof. J. J. Sederholm, the Director of the Geological Commission, has done everything in his power to facilitate my work, and I am very grateful to him. Dr. Benj. Frosterus first suggested that I should make this interesting region a subject of treatment. Being my superior in the survey, he made several excursions with me and in many ways furthered my work with his personal knowledge of the region. Moreover, he kindly allowed me to use the results of his own exploration of the Skogböle tract. For all this I thank him very cordially.

I am also very much indebted to Professor W. G. Fearnsides of Sheffield who kindly corrected the English of a great part of my manuscript.

Introduction.

Petrological divisions.

The Archaean formations of Southwestern Finland can be divided petrologically into *nonmetamorphic* (or *feebly metamorphic*) *rocks* and *markedly metamorphic rocks.*

To the former division only those granites belong which in Finland have often been called *granites of the coast type.* They are generally characterized by a prevalence of potash over soda, which shows itself in the mineral composition by the development of an abundance of microcline. As this character is very constant in the area treated in this paper, this series will be termed the *microcline-granite series.*

The metamorphic division comprises an *infracrustal* and a *supercrustal* series of rocks.

The infracrustal series forms masses composed of various rocks which are believed to be of consanguineous origin, and do not vary much in age. They are all typical rocks of the Pacific kindred, and range from granites to peridotites. In the granites soda is characteristically prevalent over potash, and plagioclase, varying from albite to oligoclase-andesine, is the most abundant feldspar. In accordance with this characteristic, this group of granites are here termed *oligoclase-granites.* The degree of their metamorphism is variable: some examples are almost unaffected, others are perfectly crystalloblastic.

The supercrustal series of metamorphic rocks comprises fine-grained gneisses or *leptites*, and *amphibolites*, often called in Finland »metabasites», and *crystalline limestones.* To the leptites belong rocks which originally were in part ordinary sediments, in part volcanic lavas, tuffs and ashes. The amphibolites most probably are of a volcanic (in part hypabyssal) origin, though a group of them (the diopside-amphibolites) are possibly mixed with sedimentary material. The limestones are believed to be ordinary sediments.

In most cases the metamorphosed supercrustal rocks can be easily distinguished from those of an infracrustal origin; but the metamorphic gabbros and diorites are sometimes petrographically almost identical with the amphibolites of a supercrustal origin.

Furthermore there are rocks intermediate between those two groups, or showing gradual transitions from one group to the other.

It must be remembered that the explanation of the leptite formation as a metamorphosed supercrustal series has not yet been unaminously accepted by the petrographers who are at work in Sweden where formations not unlike those now under consideration occur. That this explanation is nevertheless given here without restriction or reservation, is due to the fact that the present writer during his work in southwestern Finland has become convinced of the supercrustal origin of the leptite series, and has accepted Holmquist's conclusions concerning the Utö territory in the coast-regions

Table I.

Quaternary	Glacial and post-Glacial deposits.
	Hiatus.
Cambrian	Sandstone dikes and casts.
	Hiatus.
Post-Jotnian Eruptives	Olivine-diabase in Satakunta and related dike-rocks.
Jotnian	Sandstone in Satakunta.
	Hiatus.
Sub-Jotnian Eruptives	Rapakivi and related granites.
	Great hiatus.
Archaean	Microcline-granites.
	Hiatus.
	Amphibolite dikes. Aplite dikes. Oligoclase-granite. Diorite, gabbro and peridotite.
	Leptites, amphibolites and limestones.

of Stockholm. [1] It is believed that sufficient evidence in favour of this opinion will be given in the course of this treatise.

Geological sequence. The geological relations of the Archaean formations of southwestern Finland are expressed in table I where, in order to give a complete view of the formations existing in this part of Finland, the relations of the post-Archaean formations are also shown.

Remarks on the tectonics. By far the largest part of southern Finland is underlain by a complex mixture of various metamorphic rocks intimately injected with microcline-granite which mixtures have been called migmatites by Sederholm. All degrees of transition may be found there from rocks entirely assimilated with the granite through the most thoroughly mixed arterites to less intimate mixtures. The fragments of the invaded rocks often attain considerable dimensions, and there are some areas where they have nearly or entirely escaped the injection with granitic magma. One of the largest of such areas is that district of metamorphic rocks which can be followed from the archipelago of Hiittis in an eastnortheasterly direction, some 110 km in all, to the parish of Karis-Lojo, where it grades into an area of migmatites and microcline-granite. Some kilometers to the East, this belt, however, again appears and continues throughout the parish of Lohja. To the West also the belt of metamorphic rocks disappears in an area of migmatites.

The main part of the Archaean territory of southern Finland, situated between the rapakivi-masses of Viborg and Nystad, can be regarded as formed of microcline-granite in which the other rocks occur as isolated and fragmentary masses. However, the schistous rocks of this territory have, on the whole, preserved their original strike of approximately N 70° E. This zone of supercrustal metamorphosed schists and »older Archaean» granites, both intersected by the newest Archaean or ser-Archaean granites, continues in Sweden with the same general strike and there preserves the identical characters of the main rock-series. The whole zone, regarded as the denuded roots of an ancient mountain chain, has been termed *»the Sveco-Fennian range»*.

The microcline-granites surrounding the leptite-belt always show typical intrusive contacts towards the latter. Quartz-porphyritic contact-modifications are not found, and the apophyses starting from the granite always show an aplitic or pegmatitic habit.

Within the leptite belt, the infracrustal rocks are younger than the supercrustal series, but in contact-phenomena as well as in their

[1] »The Archaean Geology of the Coast-regions of Stockholm», *G. F. F.*, *32*, p. 789, 1910.

whole geological appearance the eruptive series of the oligoclase-granite shows a striking difference from the behavior of the microcline-granites. Fine-grained and quartz-porphyritic contact-modifications are common. The boundary lines towards the schists generally run conformably with the strike of the latter. Pegmatitic modifications are uncommon, and the oligoclase-granites never show the typical phenomena of assimilation and migmatitization which so universally accompany the microcline-granite. The conclusion may very well be drawn that the oligoclase-granites are not such typically deep-seated eruptive rocks as are the microcline-granites, but that they have been solidified nearer to the earth's surface. Certain rocks of the supercrustal series are probably connected genetically with the oligoclase-granites, being perhaps products of volcanic eruptions fed by the same magma which later on solidified to form the granites, diorites etc.

As was already pointed out by Tigerstedt in the case of the Orijärvi batholith, the batholiths of the oligoclase-granites, moreover, seem to fill up anticlines of schists. As this author remarks, the schistous rocks bounding the granite at the northern side are identical with those at the northern side of the batholith. I found furthermore that the tilted strata north of this granite form a continuous series (see map II), each horizon being characterized by some constant feature. Nearest to the granite there are leptites intercalated with numerous beds of limestone and effusive amphibolites, all dipping to the north at 50° to 70°. North of a larger sill of amphibolite, a bed of blasto-porphyritic leptites, i. e. originally quartz-porphyries, occurs overlain by a bed of effusive amphibolite, which at its northern wall grades into porphyrites, amygdaloids and agglomerates. Here the layers assume a nearly vertical position. To the North a horizon of a peculiar composition follows, characterized by diopside-amphibolites, interstratified with leptite and narrow beds of limestone. This horizon grades into alternating leptites and amphibolites, and north of Vetjo a bed of cordierite-bearing leptite, rich in biotite, is found. This bed has the composition of a clayey sediment and forms a continuation of the horizon which further west is developed as a cordierite-leptite. Further to the North there are leptites and amphibolites often showing well preserved traces of volcanic structures, but here the strata are disturbed by numerous intrusive bodies, and it cannot be decided whether they belong to the main series or not.

If the formations north of the Orijärvi batholith are regarded as a single series of strata, the oldest part of which is bounded by the granite, this series has a thickness of more than two kilometers.

In other parts of the leptite belt the tectonics are not so simple. At the southern side of the Orijärvi batholith only a narrow band of leptitic rocks occurs, probably as a wedge pressing between the Orijärvi granite and the larger granite-mass south of Lake Määrijärvi. It may be noted that limestones also occur at the southern side of the last-named batholith near the station of Skogböle, in immediate contact with the oligoclase-granite.

Over the major portions of the area the layers are arranged in almost vertical positions, and it seems impossible to interpret the se-

Fig. 2. Folded layers of limestone intercalated with leptite and amphibolite. Hepolahdensaari, Orijärvi. The photograph was taken from the West.

quence of strata. Although they form seemingly uninterrupted series, there may be repeated folds or faults, which are not traceable at the earth's surface, where only a cross-section of the series is seen. A remarkable persistence of the horizons along the line of strike has been proved, in very many cases. Thus the beds of limestone can be traced for several kilometers, as for example, on the island of Kimito.

Some sections across the whole leptite belt, as that drawn over Westlax and Stenmo in the parish of Kimito, show a typical anticlinal form. Other sections, on the contrary, show a synclinal dipping of the strata; the section crossing the southern oligoclase-granite mass round Lake Tuulijärvi may be quoted as an example.

At all places, where smaller folds are seen, the axis of folding hitches always to the East, the inclination varying from 10° to 70°. Within the basin of Lake Orijärvi this reversed folding is clearly visible (fig. 2); here the inclination is only 20° or 30°.

The large batholith of oligoclase-granite north of the station of Skogböle as well as the Orijärvi batholith show marginal quartz-porphyritic contact-modifications in their western ends, while towards the East, the contact-zones become gradually unnoticeable, and the granites form eruptive breccias with and are intruded as veins into the adjacent rocks. As regards the Orijärvi batholith, Tigerstedt has already concluded that the rock-mass must have been tilted in such a way that at its western end rocks are exposed which originally consolidated at the shallowest depths. This phenomenon can also be explained on the assumption that the granite-margin dips gently beneath the adjacent rocks towards the West, and that elsewhere the contact boundary is more nearly vertical. Thus, in the former case, the contact towards the hanging wall would be exposed, as it undoubtedly is at the western end of the Orijärvi batholith.

The rocks of the leptite area, including the oligoclase-granites and other infracrustal rocks, form a tectonic unit, bounded on all sides by the microcline-granite mass. Considering the enormous areas underlain by the latter, it can be regarded as a consolidated and denuded part of former infracrustal magma basins. It is perhaps not appropriate to speak of the eruption of the microcline-granite, for it is possible that during an orogenetic period parts of the lithosphere may have sunk down into the magma. By such a process much rock was assimilated or migmatitized by the granite, but wherever the down-pressed parts were coherent, they have retained their structure and composition. The influence of the surrounding magma has, of course, left its stamp on the whole series enclosed in it. In the leptites under consideration, this influence was strongest in the middle part of the belt where granitic intrusions were abundant and all the leptites were changed into highly metamorphic gneisses. Eastwards the degree of the metamorphism and granitization decreases gradually, whilst to the West, the sound of Strömma indicates a tectonic line, west of which the degree of metamorphism at once decreases to a minimum.

The geological development. The oldest rocks are of supercrustal origin. At their base there occurs a group of infracrustal rocks which is newer than the former and intrusive in it. The interrelations of the two series are the same which have also been found to be usual in the Archaean of Sweden and in the Keewatin of Northern America.

As to the oligoclase-granite group, I agree with Tigerstedt (cf. page 5) in regarding its eruption as connected with the folding. A certain evidence of mechanical disturbance no doubt dates from a period posterior to the consolidation of the oligoclase-granites, but there are also very distinct protoclastic features, indicating movements during their crystallization. The conformable boundaries towards the leptites also can be best understood, if the granites have been brought up contemporaneously with the raising of the strata.

After solidification the oligoclase-granites were intersected by dike-rocks which have now the habit of amphibolites. Probably they were originally pyroxene-bearing basaltic or diabasic rocks. Much stress has been laid on the evidence provided by such dikes, in an adjacent region, by Sederholm, who regards these rocks, which he terms metabasalts, as proofs of a denudation posterior to the eruption of the older Archaean (or pre-Bothnian) granites. It must, however, be remembered that the oligoclase-granites themselves have consolidated under conditions which were in part hypabyssal and that the temperature in the surrounding rocks was doubtless considerably lower than that in the magma, and that their apophyses are often like volcanic rocks. Secondly, no true supercrustal Archaean rocks newer than the oligoclase-granite have been found in the region in question, nor have conglomerates containing infracrustal rocks as boulders been found here in any Archaean series. It seems therefore to the present writer, that no true unconformities can be traced within the Archaean areas under consideration.

The amphibolite dikes are the newest of the metamorphic rocks. It was after their eruption that the part of the rock-crust which now forms the leptite belt was pressed down by orogenetic movement into great depths, and, as a coherent body, was finally immersed in the microcline-granite magma.

Thereafter followed an immense period of denudation, of which we only know that already in the Jotnian time nearly the same levels which now form the actual land-surface were exposed.

Preliminary remarks on the metamorphism.

If it is right to suppose that the mountain folding had begun already before the eruption of the oligoclase-granites, it is probable that the other rocks had been somewhat metamorphosed by the influence of stress before that time. The first considerable metamorphic process, however, was the contact-metamorphism caused by the oligoclase-granites. It was partly thermal, partly of a pneumatolytic nature. Its effects are fairly well traceable in the rocks adjacent to the oligoclase-granites and will be one of the chief subjects of the present treatise. At the time immediately after the eruptions of the oligoclase-granites, the formations probably would have presented an aspect which is actually seen round many Middle-European granite masses: The granites were surrounded by metamorphic aureoles, while, at a distance, the rocks were comparatively little changed.

During subsequent periods, the orogenetic movements no doubt gave rise to metamorphic changes in the rocks. These are traceable especially in the oligoclase-granites themselves.

Fig. 3. View over Lake Orijärvi from the East. A typical landscape-form of the Orijärvi region.

The latest metamorphism was caused by the great masses of microcline-granite, the influence of whose contact-metamorphism is, no doubt, most conspicuous in the formation of the crystalline schists. At the boundaries which adjoin the microcline-granites, the schist have been most changed: the leptites are converted into medium-grained gneisses, the amphibolites have become more coarsely crystalline, and all their primary characteristics have been obliterated. Farther from the contact the changes are less marked and become gradually smaller, but everywhere the rocks are characterized by newly formed minerals. The character of the metamorphism is very uniform throughout the wide area, and may well be spoken of as *regional plutono-metamorphism.*

Microcline-granite.

The Perniö granite.

The granite from Sillanpää in Kisko.

The granites which surround the area of crystalline schists are all characterized by a high proportion of potash which, for the most part, is found in the microcline, and for this reason the name microcline-granite is applied to designate them. As typical of their chemical composition we may take an analysis made by the writer, of a coarse-grained, porphyritic, garnet-bearing pale-red granite from Sillanpää in the parish of Kisko, near the western limit of the Kisko leptite area (table II).

Table II.

		Mol. prop.	Mol. %	Norm		Mode	
SiO_2	73.91 %	1.232	81.0	Q	31.80 %	Quartz	32.2 %
Al_2O_3	13.90 »	.136	9.0	Or	38.36 »	Microcline	37.3 »
Fe_2O_3	0.14 »	.001	—	Ab	20.44 »	Albite	20.5 »
FeO	1.01 »	.015	1.1	An	5.00 »	Anorthite	5.0 »
MnO	trace	—	—	Cor	1.02 »	Lepidomelane	2.4 »
MgO	0.28 »	.007	0.5	Σ sal	96.62 »	Almandine	1.8 »
CaO	1.00 »	.018	1.2	Hy $MgSiO_3$	0.70 »		99.2 »
Na_2O	2.42 »	.039	2.5	Hy $FeSiO_3$	1.45 »	Al_2O_3 in excess	0.3 »
K_2O	6.53 »	.069	4.5	Mt	0.23 »		
TiO_2	0.22 »	.003	0.2	Il	0.46 »		99.5 »
H_2O+	0.33 »	—	—	Σ fem	2.84 »		
H_2O-	0.19 »	—	—		99.46 %		
	99.93 %	—	100.0				

D e l l e n o s e.

Osann's system:	s	A	C	F	n	a	c	f	k
	81.2	7.0	1.2	1.6	3.6	14.5	2.5	3	1.76

This rock consists chiefly of the minerals mentioned above under the mode. This was calculated from the analysis on the basis of a microscopical examination, assuming all Fe_2O_3, FeO, MgO and TiO_2 to enter proportionally into the mica and garnet and rating approximately the proportions of these minerals at 4 : 3. The analysis shows a prevalence of FeO above MgO, and the optical properties of garnet and mica also prove that they are both rich in iron. The mica is reddish brown in unpolarized light and with one nicol it shows a strong pleochroism: $\mathfrak{a}$ = pale brown $< \mathfrak{b} = \mathfrak{c}$ = black opaque. Hence it is a l e p i d o m e l a n e. The garnet megascopically is red, a faint tint being even traceable in thin sections. It is perfectly isotropic. Its refractive index is higher than 1,782. Consequently, it can be classed with the a l m a n d i n e s.

The assumption that all femic oxides are present in lepidomelane and almandine is not strictly correct, small amounts of green c h l o r i t e occurring as a product of alteration of the two above minerals and t i t a n i t e also having been observed. These minerals, however, are present in such trifling amounts that their total quantity probably would be less than 0.1 percent. No apatite was detected microscopically, nor any iron ores. Red pigment is abundant in the microcline. Quantitatively of greater importance, no doubt, are the turbid products of alteration of the plagioclase, which, when coarse enough to allow of microscopical determination, were found to consist of small flakes of m u s c o v i t e. To them may be ascribed the excess of 0.30 % Al_2O_3 after the calculation of the residue as feldspars and quartz.

According to the analysis, the plagioclase possesses the composition $Ab_{81}An_{19}$. Microscopically it was found to be zonally built, the maximum extinction angle in the kernels being about 0°, corresponding to a mixture $Ab_{79}An_{21}$,[1] and in the borders 15°, with ω of quartz $> \alpha_1$, leading to $Ab_{93}An_7$. The transition of the zones is quite gradual. The more calcic inner parts have been much altered, whilst the albitic borders are sometimes almost clear. A nearly pure albite occurs abundantly as a perthitic intergrowth in the microcline. Where the plagioclase is limited by the latter, it is bordered with a zone of albite, 0.06 mm thick or less. Between plagioclase and quartz there is no such albitic border, a phenomenon observed also by Mäkinen [2] in the microcline-granites from Tammela.

[1] In the determination of the plagioclases by means of the extinction angles the diagrams given by H. Rosenbusch, in »Mikroskopische Physiographie» I. 2. (4 Aufl.), were used.

[2] *Bull. Comm. Geol. Finl.* **35**, p. 8, 1912.

Various types of the microcline-granite.

The analysis given above was made of a specimen from a very uniform rock wich forms the extensive mass, shown on map I. Of course, this one analysis cannot claim to give any idea of the bulk composition of the whole area designated as microcline-granites. Microscopical study of the rocks from different localities in the area surrounding the belt of the crystalline schists proves, however, that their composition must be fairly uniform. The rocks always contain q u a r t z, and m i c r o c l i n e in excess of p l a g i o c l a s e, and they are poor in mafic minerals, l e p i d o m e l a n e being invariably present. M u s c o v i t e occurs frequently, but is never abundant. It mostly appears as a product of alteration of the feldspars. Furthermore the scarcity or absence of the accessory constituents is very characteristic. Of these: t i t a n i t e, a p a t i t e, z i r c o n and i r o n o r e s occur. A l m a n d i n e is of widely spread occurrence as a regular constituent. The pegmatitic varieties not infrequently are c o r d i e r i t e - bearing, especially in the northern part of the parish of Kisko.

Microcline-granites form the main part of the rock-crust over the whole of southern Finland, where they are known as the »granites of the coast-type», or alternately as the »post-Bothnian granites». Chemically they are as yet very little known, but there is scarcely any doubt that the main part of them belongs to types rich in potash. For comparison two analyses may be given of the Hangö granite from an area south of the leptite belt, but belonging geologically to the same formation as the microcline-granites under consideration.

I. Granite (toscanose) from Drottningberget in the town of Hangö, analyst I. G. Sundell.[1]

II. Granite (dellenose) from the island of Skarfkyrkan, east of Hangö, analyst L. Hezner.[2]

	I	II
SiO_2	73.18 %	71.75 %
Al_2O_3	13.71 »	14.13 »
Fe_2O_3	0.52 »	1.12 »
FeO	1.22 »	1.37 »
MnO	0.01 »	trace
MgO	0.37 »	0.64 »

[1] V. Hackman, »Die chemische Beschaffenheit von Eruptivgesteinen Finlands und der Halbinsel Kola», *Bull. Comm. Geol. Finl.* **15**, 1905.

[2] J. J. Sederholm, »Om palingenesen i den sydfinska skärgården», *G. F. F.* **34**, p. 304, 1912.

CaO	1.22 %	1.59 %
Na_2O	2.40 »	2.25 »
K_2O	5.70 »	5.85 »
TiO_2	0.21 »	0.18 »
P_2O_5	0.05 »	0.07 »
H_2O	0.69 »	0.83 »
	99.28 %	99.78 %

Despite their very constant chemical composition the microcline-granites show a great variability of structure. Two types are especially important: the one coarse-grained and porphyritic (»Augen-structur» according to the terminology of Holmquist), and another of medium texture and even grain.

The former type is represented by the specimen from Sillanpää whose analysis is given above. It forms a homogeneous mass, more than 75 km in length and from 10 to 15 km in breath. The middle and largest part of it underlaying a large part of the parish of Perniö, it may be termed the Perniö granite.

The even-grained microcline-granites are represented by several types differing in their colours, well known as the red Hangö granite and the grey Hiittis granite, because used for industrial purposes. Rocks of the Hangö type are commonly met with in the granite areas east and south of the leptite belt. The Hiittis granite is worked on the island of Bergö, south of Dalsbruk, and in the village of Lammala in the parish of Westanfjärd. Grey microcline-granites occur abundantly in the southwest of the area on map I, in the archipelago of Hiittis. Though different in colour, no difference in composition can be detected, and even the colour is not constant, but here and there passes gradually into more or less intense red tints.

Geologically, the medium-grained and coarse-grained granites belong to the same formation. Gradual transitions between them may be observed in all parts of the area. Thus in the northeastern part of the Perniö massive, the coarse granite grades into a red Hangö granite, and along its boundary towards the leptites a narrow zone of medium-grained grey-coloured variety generally occurs. In the eastern and southern areas the medium-grained granites frequently graduate to the coarse-grained porphyritic granites. The connection is especially apparent in the parish of Bromarf, southwest of Tenala, where wide areas are formed of a granite of the Perniö type. Here it may be seen that the coarsely crystalline »augen» structure is developed wherever the rock occurs as a large mass and is free from fragmentary inclusions of other sorts of rocks. Smaller masses — only some hundred meters in diameter —, dikes and rock-masses mixed with abundant fragments of schistous rocks have been developed as granites of the Hangö or Hiittis type.

The structure of the Perniö granite.

The Perniö granites are mostly greyish red or pale red, occasionally deep red, as the granite worked at Viik in Kimito. The porphyritic habit is more pronounced in varieties which are devoid of garnet; in these the large crystals of microcline are often 3 cm and more in length. No plagioclase can as a rule be discerned with the naked eye.

Often, as in the eastern part of the northern area, from which the analyzed specimen was taken, the rock is perfectly massive. The primary habit being here preserved in its most typical form, we may begin the study of the structures with a description of the microscopic characteristics of the rock specimen which was analyzed.

A marked sequence of crystallization is at once apparent. The first mineral to separate was the lepidomelane, which occurs as euhedral or corroded crystals, and is included in all other constituents. It is even older than the almandine. The almandine is found as sparingly scattered crystals of about 10 mm in diameter, and its crystals contain rounded inclusions of quartz. Where crystals of dark-coloured mica are enclosed in the garnet, they are surrounded by extremely thin needles of a colourless birefractive substance which shows a positive elongation. Probably it is sillimanite. The relations of the garnet and the felsic minerals are not clear, as the former only was observed in contact with anhedral quartz.

Among the felsic constituents, the plagioclase shows the highest degree of idiomorphism. If not too much modified by the corrosion, the crystals are euhedral, when enclosed in the microcline or quartz. Embedded in the microclines there are also crystals of quartz which, although mostly less idiomorphic than the plagioclase, seem to have crystallized earlier than the latter, and occur as similar inclusions in the plagioclases, too. These enclosed crystals are usually rounded or have irregular shapes, resembling the corrosion forms of quartz in volcanic rocks. At times a crystalline form may be traced, and a few quite well preserved bipyramids have been observed. Such bipyramids of quartz show rectilinear boundaries towards the feldspars. Besides the enclosed and partly idiomorphic crystals of quartz there is another kind of quartz which apparently was the last mineral to separate. Against this quartz the microcline has often developed its own crystalline forms. The latter mineral builds up the largest individual crystals of the rock, 15 mm in diameter, and gives the rock its porphyritic appearance. There is, however, no marked difference between the »phenocrysts» and the ground-mass, and crystals of microcline of all sizes down to less than 1 mm in diameter occur. The big microclines are always twins of the Karlsbad type.

The phenomena of corrosion are well developed and merit the closest attention. Most conspicuous they are at the boundaries between microcline and the xenomorphic quartz, the contact-lines of which show characteristically sinuous curvings, and give the impression that the quartz has corroded the feldspar (pl. I, fig. 1). The largest crystals are most corroded, the smallest ones, included in the quartz, very little or not at all affected.

This phenomenon is apparently identical with the »quartz de corrosion» of the French petrologists, and it has frequently been mentioned as an interesting feature of many Fenno-Scandian granites. Thus H. Bäckström [1] has given a detailed description of such »corrosion quartz» in the Halen granite in Blekinge, Sweden, which must be very similar to that of the Perniö granite. The phenomenon in question is interpreted as follows (1. c. page 116): »The writer considers the differences from the hypidiomorphic structure in these granites as owing to a sort of corrosion, but secondary not primary, due to the beginning of the crushing of the rock and probably also in some degree to the beginning of decomposition, and consequently not the result of circumstances accompanying the original crystallization of the granite magma.»

Holmquist [2] is of the same opinion: »Alle diese Strukturzüge (quartz de corrosion, quartz vermiculé) sind dem Granit und Gneiss der metamorphischen Gebiete eigen, und sie kommen in ganz unmetamorphosierten Graniten nicht vor.»

This theory of the secondary origin of all »corrosion quartz» seems to be generally accepted by all Fenno-Scandian geologists and is even regarded as one of the most important differences between the Archaean and the post-Archaean granites. The present writer has, however, been led to a different conclusion, and will state his reason as follows.

The phenomena of corrosion are not limited to the boundaries between quartz and microcline but appear in a very constant manner at the boundaries between all other minerals. In the case of microcline

[1] »Vestanåfältet», *K. Sv. Vet. Ak. Förh.* **29**, N:o 4, p. 9—13, and the English summary, p. 116, 1897.

[2] »Studien über die Granite von Schweden», *Bull. Geol. Inst. Univ. of Upsala*, VII, p. 116, 1907.

and quartz it is evident — in the Perniö-granite as well as in other related granites — that the former has been corroded, the latter having filled up the spaces thus originated. The relations may be interpreted in exactly the same way in every case, and the simple rule, that the order of corrosion is always opposite to the order of crystallization is found to hold good. Thus the last crystallized quartz has corroded all other minerals, microcline all but this quartz, and plagioclase only the idiomorphic quartz and lepidomelane. The manner of the corrosion is somewhat variable and the forms developed characteristic of the individual minerals: In the feldspars sinuous or sometimes almost serrated lines are favoured, the quartz more often assumes simple rounded forms, whereas the mica takes on fringed forms with sharp edges. All these phenomena are often distinctly observeable under the microscope in one single field of vision.

In the opinion of the writer the simplest and most natural way to understand this structure is to regard it as a product of crystallization accompanied by magmatic corrosion. The physico-chemical theories of the crystallization of solutions have shown, that the phenomena of resorption may take place as a normal event in the regular course of crystallization, by reason of the progressive change of composition of the residual solution. In the case of viscous solutions like the granite magma, it seems probable that phenomena of supersaturation may also play an important part. Exact knowledge of the granitic system not being available at the present time, the process of crystallization could perhaps be outlined approximately as follows.

The mafic constituents being quantitatively insignificant, the original magma may be regarded as a mutual solution of felspars and quartz. Silica being present in excess of the »quartz-felspar eutecticum»,[1] requiring 27.5 % quartz and 72.5 % feldspars, the crystallization had begun with a separation of quartz, this being in accordance with Vogt's theory. The crystallization of quartz continued after the residual magma had attained the eutectic composition, though the magma had now become supersaturated with the feldspar-compounds. At the metastable limit of the feldspar its incipient crystallization caused a liberation of heat, and some of the quartz was resorbed. When the main part of the feldspars had

[1] J. H. L. Vogt, »Physikalisch-chemische Gesetze der Kristallisationsfolge in Eruptivgesteinen», *T. M. P. M.* **25**, p. 384.

separated, the residue was highly supersaturated with quartz,[1] whose final consolidation in the beginning gave rise to the corrosion of the feldspars. The redissolved microcline again crystallized into idiomorphic forms previous to complete consolidation of the rock. Thus it is explained why the smallest crystals of microcline, included in the quartz, show the best preserved crystalline forms (pl. I, fig. 2).

Among felspars the plagioclase regularly shows crystalline forms towards the microcline. The opposite case never was observed. Thus it would seem probable that the former had separated earlier, which, however, does not accord with the theory of the eutectics. In the Perniö granite, like most microcline-granites, microcline is in considerable excess of the plagioclase, the »ternary granitic eutecticum» according to Vogt requiring 30.5 % Or and 42.0 % Ab. Thus the microcline ought to be the first separated feldspar. Possibly it was so, for it is a matter of fact, that inclusions of plagioclase are very sparingly found in the inner part of the big microclines. A further epoch of supersaturation and corrosion at the incipient crystallization of the plagioclase would explain the absence of idiomorphism in the microcline. No facts can be regarded as proofs of such a supposition and the circumstance must remain undecided. I only wish to point out that the order of idiomorphism is not necessarily identical with the order of crystallization.

If the corrosion quartz is to be interpreted as a product of regional-metamorphic origin in the sense of Bäckström and others, the corrosion boundaries would be, in the case of the granite from Sillanpää, the sole evidence of the metamorphism. There are no granulated portions between the larger crystals (mortar structure, Törnebohm). Undulatory extinction in the quartz is not more developed than is usual in all granite, however non-metamorphic. Myrmekite which by some authors is interpreted as a product of metamorphism was not detected in this granite. That the inappreciable amount of newly formed chlorite and muscovite observed is not to be regarded as a proof of regional metamorphism, seems to the writer to be a circumstance requiring no discussion. The circumstance that the

[1] It may be objected, that any further supersaturation with quartz is impossible, as quartz is already present. But the phenomenon in question can hardly be interpreted in any other way. Perhaps inoculation in such viscous magmas does not take place (cf. Harker, »The Natural History of Igneous Rocks», 1909, p. 210), or the previous quartz-grains were wholly enveloped by the feldspar and were not in contact with the last portion of the magma (Harker, op. cit. p. 268).

microcline, originally consolidated as an isomorphous mixture saturated with soda feldspar, had thrown out albite in the form of perthitic laths or zones surrounding those plagioclases adjacent to the microcline, is a phenomenon which is associated with the slow cooling of the mineral and is no evidence of the interference of regional metamorphism. In one word, there is no feature suggestive of the onset of such agencies. It may be remembered that the petrologists who have regarded a secondary origin of the corrosion quartz as probable, have never given any positive evidence for this supposition, but have only pointed out the fact that it is accompanied by other phenomena, which are regarded as being associated with the phenomena of metamorphism.

On the other hand, the sinuous boundaries between microcline and quartz show forms vividly resembling corrosion forms in many other rocks, e. g. the idiomorphic plagioclase-laths embedded in augite, as in the diabases of the Åsby type.

The sinuous boundary-lines between quartz and microcline, perhaps in its most typical and well developed form, are found in the pegmatites which accompany the microcline-granites. In pegmatites a graphic intergrowth of microcline and plagioclase is common. It is of importance that in this case the mutual boundaries of the minerals are generally nearly rectilinear and show no typically sinuous form. It seems evident that in both cases equally the structure is original. In the graphic intergrowth, quartz and feldspar crystallized contemporaneously and the consolidation was not accompanied by corrosion, while elsewhere the crystallization took place in a certain sequence and was accompanied by a considerable magmatic corrosion of all but the last crystallized minerals.

The writer therefore regards the structure of the Perniö granite from Sillanpää as a true structure of consolidation and with no secondary features. This granite is characterized by the corroded forms of all its constituents except of that quartz which was the last portion to consolidate.

The granite from Sillanpää is perfectly massive, as is the rock in wide areas of the eastern part of the Perniö batholith and occasionally in other parts, too. More often, especially in the middle and western portion, there is a more or less well developed foliation parallel with the elongation of the batholith and thus conformable to the strike of the adjacent leptite belt. This foliation is mainly owing to the arrangement of the individual large Karlsbad twins of microcline with their faces (010) almost parallel. Here and there an occasional crystal is found in a transverse position, and the smaller individuals are quite irregularly arranged. Quartz usually forms a part of the granulated mass but occurs also as larger individuals which fill up the spaces between the large microclines. These larger individuals of quartz are quite anhedral and are elongated parallel to the foliation of the rock.

All the feldspars when broken show only continuous cleavage planes with no trace of any deformations. Thus even under megascop-

Fig. 4. Perniö granite showing parallell structure. Metsänoja, north of Haarla, Perniö. Autotypy from hand specimen in natural size.

ic examination, it seems evident, that foliation has not been caused by any pressure on a solid mass, but is a result of a movement of the magma during its process of consolidation. This conclusion is corroborated by microscopic examination. A specimen from the village of Metsänoja in Perniö, illustrated by fig. 4, may be taken as typical. The sequence of idiomorphism is the one usual in these granites: dark mica, plagioclase, microcline, quartz. The phenomena of corrosion are identical with those described above, and the individual grains do not show any mechanical deformations, although granulation is observed on a large scale. From many of the large microclines smaller fragments have been broken away and are now observed at some distances from the main crystal — a phenomenon which can only be understood as a result of crushing during the time when the large feldspars were suspended in the residual magma.

Myrmekite in the Perniö granite.

M y r m e k i t e is present in abundance in this particular specimen as well as in many other samples which show fluxion structure in the Perniö-granite. As this suture-like implication of quartz and plagioclase at the boundaries of the potash feldspars is often regarded as a proof of metamorphism posterior to the consolidation of the rock, the writer's observations upon this subject, (which do not confirm this opinion) are summarized below. For the characteristics of »myrmekite», it suffices to refer to an article of Becke.[1] Here I will only mention what new facts I have to add to this description.

1. Becke remarks as an important characteristic: »der Myrmekitfeldspat grenzt sich gegen Kalifeldspat stets durch konvexe Flächen ab.» In the microcline-granites from southwestern Finland a plagioclase-quartz mosaic with sutured boundary is frequently found with all the characteristics of the myrmekite, but with rectilinear boundaries against the microcline, i. e. the myrmekite feldspar apparently is idiomorphic (plate I fig. 3). In the same rock there is also some myrmekite showing the usual curved outlines, and it seems that the former originated at a later period than the latter. The idiomorphic myrmekite-plagioclase is turbid like the average plagioclase of the rock. Generally such a myrmekite occurs where the microcline is bordered by somewhat large individuals of quartz or plagioclase, or where inclusions in the microcline are developed as myrmekite. At times the myrmekite was seen to be bordered by a clear zone of albite, similar to that occurring around other plagioclases. No quartz imbrication having been found in the clear border zone, it is probable that the separation of the albite from the microcline took place after the time when the myrmekite was formed. The myrmekite with curved outlines, on the other hand, is clear like the newly formed albite surrounding the plagioclase, and it occurs, as a rule, at places where the big microclines are bordered by the granulated mass.

2. »Gesteine mit ganz reinen Erstarrungstrukturen scheint er zu meiden, wie schon Sederholm für die Rapakiwigesteine hervorhebt». I have, however, observed true myrmekite in several rapakivi-granites, e. g. in a specimen from Kavantsaari, in eastern Finland, and also in

[1] »Myrmekit», *Denkschr. Ak. Wiss., Wien*, LXXV p. 137—139, 1913.

small amounts in a »typical» rapakivi from Luumäki, district of Wiborg. In both cases the myrmekite was formed as a continuation of idiomorphic plagioclase bordered by the potash feldspar.

3. »Nicht zu verkennen sind seine Beziehungen zur Krystallisationsschieferung. Mit dieser ist er durchaus verträglich; nur ist hervorzuheben, dass er auch in Gesteinen auftritt, die von Schieferung überhaupt frei sind.» Besides this I wish to point out that granitic rocks of partly granoblastic structure may be devoid of myrmekite. Thus in the oligoclase-granites from the Orijärvi area, described later on, the myrmekite is of rare occurrence. It is seen that an advanced metamorphism was not able to produce any myrmekite.

As to the origin of the myrmekite, the conclusion of Becke is as follows: »Wenn man aus diesen Tatsachen einen Schluss ziehen dürfte, so ist er der, dass die Myrmekitbildung sich in einer Phase der Gesteinsbildung zu vollziehen scheint, die sich unmittelbar an die Erstarrung anschliesst, also zu einer Zeit, wenn die Temperatur noch der Erstarrungstemperatur nahe steht und noch Lösungsmittel im Gestein vorhanden sind». This conclusion is in accordance also with the facts mentioned above, only it seems probable that the myrmekite in part may have originated already during the process of consolidation. In any case, the presence of the myrmekite cannot be regarded as a sign of regional metamorphism.

Thus it seems that in the already partly crystallized magma fluctuations took place caused by stress acting in the same direction as that which had folded the supercrustal rocks in the leptite belt. To these movements of the magma probably are due the phenomena of crushing and granulation observed in the rock, as well as its frequently marked foliation. No features were detected which proved positively that any movement had taken place in the rock after its complete consolidation.

Non-metamorphic Archaean granites compared with the sub-Jotnian granites.

According to Holmquist (op. cit.) the rapakivi-structure is a true primary structure proper to the granitic igneous rocks, whilst the structures of the Archaean granites are due to metamorphic changes, which were originally identical with those of the rocks of the rapakivi series. In order to compare the structures of these two kinds of rocks, the writer has studied a number of thin sections of sub-Jotnian granites from several Fenno-Scandian regions, more especially from the rapakivi area of Nystad with which he has become familiar by explorations in the field. As this comparison brings out several characteristics bearing on the nature of the granites under consideration, they may be referred to in some detail. A few other geological considerations may also be mentioned.

In the writer's opinion the differences between the nonmetamorphosed post-Archaean granites or, to restrict the discussion to a well defined group, the sub-Jotnian granites, and the best preserved of the Archaean granites [1] are essentially of a primary character. The differences may be considered in three groups as follows.

1. Chemical difference. The chemical composition, as obtained by quantitative analysis, of many sub-Jotnian granites, especially the large rapakivi batholiths, is almost identical with that of the Archaean microcline-granites. There is, however, a striking difference which, although quantitatively so small that it does not appear in the results of the average rock-analyses, is very evident upon microscopical examination: Every slice of the sub-Jotnian granites examined by the writer contained an appreciable amount of fluorite, a mineral which he never chanced to find in any Archaean granite. The invariable presence of fluorite in the sub Jotnian rocks from Sweden, of which I have only seen a few slices, is commented on by Högbom, Holmquist and Sobral. There is also a notable difference in the character of the inclusions in the quartz. In the sub-Jotnian granites a large majority of the minute inclusions in the quartz are solid; cavities containing fluids with movable gas bubbles were rarely observed. The substance of these inclusions shows a low refringence, and is probably fluorite. In the Perniö granite, on the other hand, fluid inclusions in the quartz are very abundant.

It is evident, especially from the experiments of Tammann, that different mineralising agents may exert a considerable influence on the structures developed in the crystallization of magmatic solutions. According to the analysis made by N. Sahlbom and published by J. M. Sobral,[2] the sub-Jotnian granite of Ulfö, Sweden, contains 0.21 % fluorine. This quantity is no doubt sufficient to play the part of an important katalytic agency. The granite magma may have been still richer in fluorine, as much of this fluorine may have become concentrated in the miarolitic cavities or, having invaded the adjacent rocks, may have distributed itself elsewhere. Fluorite does in fact occur in large quantities in the pneumatolytic formations of the ore-field of Pitkäranta in eastern Finland, where according to

[1] It may be noted that the term nonmetamorphosed does not cover all that Högbom calls ser-Archaean granites which term has been applied by W. Ramsay (Geologiens grunder, II, p. 149, 1913) also to the granites of the coast-type in southern Finland. In the following the term Perniö-granite will be used in the sense defined above, but it is to be understood that this particular granite in the absence of metamorphic features is representative of a whole group of granites.

[2] »Contributions to the geology of the Nordingrå region», *Bull. geol. Inst. Un. Upsala.* XII, 1913.

O. Trüstedt [1] the rapakivi has given rise to ores and other pneumatolytic minerals. In the pneumatolytic products of the ser-Archaean granites, the scapolite is the dominant representant of the halogene-bearing contact-minerals (Pargas, Korpo etc. in southwestern Finland), and fluorite is quantitatively unimportant.

2. Geological differences. The ser-Archaean as well as the sub-Jotnian granites belong to the group of intersecting granites (durchbrechende Granite of Holmquist). In their geological characters the two groups are, however, very different. As was pointed out by Högbom more than 20 years ago, [2] the sub-Jotnian magma was susceptible to extensive differentiation. The Perniö granite, on the contrary, shows a chemical composition which is constant within very narrow limits, and apparently it has nowhere been differentiated into more femane rocks. The composition shown by the analysis of the granite from Sillanpää (page 17) represents a type which is very prevalent and which forms rock-masses of enormous dimensions.

Another characteristic feature of the ser-Archaean granite magma, contrasting strongly with the sub-Jotnian magmas, is its capacity for assimilating the rocks which it has invaded. In this way the various mixed rocks or migmatites have originated, as described by Sederholm in numerous publications. [3] At the margins of the rapakivi batholiths the phenomena of assimilation are limited to the immediate vicinity of the invading rock.

It is a remarkable fact that the composition of the ser-Archaean granites, in spite of their assimilation of various older rocks, seems hardly to be influenced by them to any considerable extent Some of its peculiarities, e. g. the occurrence of garnet, however, may possibly be due to this cause. The occurrence of garnet denotes an excess of alumina in the magma, a feature alien to normal igneous rocks, as has been recently pointed out by Osann. [4] It occurs very abundantly in some types of migmatites and as a component of homogeneous granites; its amount is variable and it is not usually present in all parts of the masses. Sederholm as long ago as 1892 [5] suggested that the

[1] »Die Erzlagerstätten von Pitkäranta», *Bull. Comm. Géol. Finl.* **19.** 1907.

[2] »Om postarkeiska eruptiver i det svensk-finska urberget», *G. F. F.* **15,** p. 211, 1893.

[3] Summarized in the article »Über die Entstehung der migmatitischen Gesteine», *Geol. Rundschau,* IV. **3,** p. 174, 1913.

[4] »Petrochemische Untersuchungen», *Alh. Heidelberger Ak. Wiss. 2 Abh.* 1. Theil, p. 21, 1913.

[5] »Om berggrunden i Södra Finland», *Fennia* **8,** p. 20, 1892.

excess in alumina might be derived from sedimentary rocks which have been assimilated by the granite magma. This hypothesis seems now very probable.

A further difference is the abundance of pegmatites within and around the ser-Archaean granite masses, and their scarcity in connection with the granites belonging to the sub-Jotnian series.

These three features of the ser-Archaean granites, i. e. their non-differentiated composition, the avidity with which they assimilate the country rock, and the abundance of their pegmatites, distinguish these rocks from the other group of granitic rocks designated as oligoclase-granites on maps I and II, which occur in the area under consideration. These »older Archaean» granites in this respect, as in many others, show more resemblance to the post-Archaean than to the ser-Archaean granites.

3. Petrographical differences. The sub-Jotnian granites are extremely variable in their structures, but have some general characteristics which are common to all the different areas. Such features are: The potash feldspar of the sub-Jotnian granites crystallized as orthoclase; and though cross-hatched microcline is often intergrown with it, the manner of the intergrowth proves that the whole was originally orthoclase, and that the alteration has developed along the cleavage-cracks or from the margins of the perthitic albite laths. In the ser-Archaean granites simple microcline occurs, associated with polysynthetically twinned microcline; and often the mode of their intergrowth is identical with that of the orthoclase and twinned microcline in the sub-Jotnian granites. The absence of orthoclase in the Archaean granites of southern Finland was pointed out by Mäkinen. [7] Since the work of this petrologist was published, the present writer has devoted some attention to this subject, and up to the present only microcline has been found. As Mäkinen pointed out (l. c. p. 78) it can hardly be believed that the untwinned microcline is derived from the orthoclase. Both must be of a primary origin, and it depends on physical conditions, whether the one or the other of these minerals is formed.

b) The potash feldspar of the sub-Jotnian granites is mostly turbid owing to abundance of pigment; in the ser-Archaean granites the potash feldspar is usually rather clear. This difference, however, is not universal.

c) Graphic intergrowths between the potash feldspar and quartz are common in the sub-Jotnian granites, but except in the pegmat-

[7] »Die Granitpegmatite von Tammela in Finnland und ihre Minerale», *Bull. Comm. Géol. Finl.* **35**, p. 77, 1912.

titic varieties have not been observed in the ser-Archaean granites. There is no reason to believe that, if this not very delicate structure had originally existed, it would have been totally obliterated from the latter group of rocks.

d) Myrmekite is rarely met with in the sub-Jotnian granites; in the ser-Archaean granites it is of a regular occurrence.

e) In many sub-Jotnian granites the biotite is xenomorphic in its relation to the quartz. In the Perniö granites most of the dark mica is decidedly idiomorphic even towards the quartz.

f) In the sub-Jotnian granites the idiomorphism of the quartz is a prominent structural character, while in the ser-Archaean granites the main part of the quartz is xenomorphic. We have already seen, that in the Perniö granite — as well as in many other varieties — idiomorphic quartz also occurs. This difference is therefore only relative, and depends on the fact that the phenomena of corrosion are more developed in the latter (Perniö) granites. In fact, in all sub-Jotnian granites except those containing micrographic intergrowths of potash feldspar and quartz, the quartz occurs in two generations: (1) as euhedral or roundly corroded crystals enclosed in feldspar or surrounding them in such a way that a part of the crystal is enclosed (Holmquist's margination structure) and (2) filling up the spaces between the feldspars and often intruding these along their cleavage-cracks. While the boundaries between the potash feldspar and the idiomorphic quartz are plane crystal faces or rounded corrosion surfaces, the boundaries of the younger quartz show the same characteristic sinuous forms which are more prominent in the ser-Archaean granites, because in these the younger quartz is more abundant and consequently the corrosion accomplished has been more considerable. Sub-Jotnian granites from different areas are very variable in this respect. In a slice of the sub-Jotnian granite from Kavantsaari, district of Viborg, the corroded quartz was found almost as abundantly as in the Perniö granite, and the structure also is nearly identical. This rock also shows a parallel structure similar with that described above in the Perniö granite.

g) Undulatory extinction in the quartz is slightly developed in the sub-Jotnian granites, but is more distinct in the ser-Archaean granites. This difference is generally believed to be due to secondary mechanical deformations of the latter rocks. According to the writer's investigations, however, undulatory extinction must in many cases also be regarded as a primary feature, as is the case with the Perniö granite. The following considerations may make this clear.

Among the numerous slices of granites from Finland and from other countries which I have examined from this point of view there was none found without some undulatory extinction in the quartz. The sub-Jotnian granites are very variable in this respect, but a careful observation showed that the differences are dependent on the structural character of the quartz itself, and not on any secondary agency. That quartz, which is graphically intergrown with the potash feldspars, shows no undulatory extinction whatever. The idiomorphic quartz shows only very slight shadows. Strain phenomena are thus inconsiderable in all the rapakivi granites containing graphic feldspar. In the xenomorphic quartz, however, the undulatory extinction is always as distinct as in the same kind of quartz of the Perniö granite (plate I fig. 1). In the Perniö granite the round grains of quartz are often almost or entirely free from strain shadows. The smaller quantity of the second generation of quartz makes the phenomenon less striking in rocks belonging to the rapakivi series. In neither group of granites does the undulatory extinction seem to have anything to do with any regional stress. A comparison with quartz which has been really deformed by mechanical factors will make this clear. Such quartz may be found in many ser-Archaean as well as in the older Archaean granites. In these rocks each individual quartz grain shows strain shadows, which really have the form of waves, each band being, on the whole, parallel to the axis of the minimum optical elasticity.[1] In other words, in any section of such a quartz cut ∥ c, the points showing the same direction of extinction form lines approximately parallel to this axis. No such phenomena were observed in the Perniö granite, and many other occurrences of ser-Archaean granites are equally free from strain shadows which are of truely secondary origin. In these rocks the undulation is irregular, the shadows stretch in various directions and often affect only one part of the crystal. Furthermore, the arrangement of the shadows often depends in some way on the form of the individual crystal grains, pieces with irregular outlines and sharp edges being especially subject to the strain.

As to the origin of the latter kind of deformed crystal-structure in the quartz, various explanations may be advanced. It seems most probable to the writer that strains in different directions are caused by the unequal contraction of the minerals during the cooling of the rock. [2]

[1] Vide: B. Sander, »Über Zusammenhänge zwichen Teilbewegung und Gefüge in Gesteinen», *T. M. P. M.*, **30**, p. 289, 1911.

[2] J. J. Sederholm (»Über die finnländischen Rapakiwigesteine», *T. M. P. M.*, **12**, p. 9, 1892) already suggested the possibility of such an interpretation.

True deformation structures are by no means rare in ser-Archaean granites. Their occurrence is the only s e c o n d a r y feature which distinguishes them from the post-Archaean granites.

Where secondary deformations occur in the porphyritic and coarse-grained varieties or in pegmatites, they are usually obvious even on megascopic examination (fig. 5): the feldspar crystals especially show a crushed appearance. Under the microscope a typical mortar-structure is usually seen. Such deformed rocks generally occur along definite tectonic lines and pass laterally into nonmetamorphic varieties. In the Perniö batholith varieties due to local crush are infrequent and ill developed. The period of their origin is probably considerably later than the consolidation of the rock.

Fig. 5. Mechanical deformation in pegmatite. 1/5 nat. size. Viiari, Kisko.

The even-grained varietes, such as those of the Hangö and Hiittis types, have usually a structure which has probably been imposed upon them by secondary deformations. In practice, however, it is ofter very difficult to discern whether a structure is truly cataclastic or protoclastic.

The migmatites.

The even-grained microcline-granites are almost always mixed with schistose materials, and the major portion of the area south of the leptite belt has therefore on map I been designated as migmatites. The character of the diverse mixtures is extremely variable. Their petrography will not be dealt with in this place, and only a few remarks on the leading types are here included.

In the southern migmatite area the types which are most common are those in which the microcline-granite forms a matrix in which more or less resorbed and assimilated fragments of metamorphic rocks are enclosed. Where the older rock has been more perfectly assimilated, only ragged gneissic remnants rich in biotite remain, and sometimes it is no longer possible to identify the rocks. But there are occasional fragments well enough preserved to be recognized as altered l e p t i t e s. Approaching the leptite area from the South, migmatites are met with in which the dominating portion consists of leptitic gneisses intersected by veins of granite. In some places these mixtures have developed as intimately and minutely veined gneisses or »arterites», the granitic part of which usually contains almandine-garnet. Such arterites, folded and contorted in detail, but, on the whole, showing the general strike of the leptite belt, may be seen along the road between Fiskars and Antskog, in the parish of Pojo. Here the individual veins are only some one or two cm thick and the gneissic bands are no thicker. At the boundaries towards the leptites the granitic veins become gradually less numerous and, becoming at the same time broader, have more the aspect of dikes. This type of transition between the microcline-granites and the leptites is met with everywhere along the southern boundary of the leptite-belt.

In the northern part of the island of Kimito, in the parish of Angelniemi, migmatitic rocks occur in which the older rock consists of g n e i s s o i d g r a n i t e s. Such migmatites are also found in the parish of Dragsfjärd and south of the area of map I. Among them all the different stages of migmatitic mixture, from brecciated mixtures to the more intimately assimilated or re-fused (anatectic) portions may be found. Within the area mapped by the writer, there are many occurrences analogous to those in the archipelago of Hangö as described by Sederholm.

Rocks of a g a b b r o i d composition, when intermingled with the granite, have offered a stouter resistance to injection by the granites than have the more salane rocks. Gabbroid fragments may occur as non-assimilated sharp-edged pieces, even where the leptites have been thoroughly assimilated; not infrequently also they form large homogeneous bodies within the migmatite area. The peridotites were still more resistant. Large and small areas of these rocks occur within highly granitized districts (e. g. north of Lake Pyhälampi in Suomusjärvi and on the island of Biskopsö in Hiittis), and through these no granitic dikes transgress, though always the contacts prove the peridotites to be older than the granite.

The resistance offered by limestones against the granitization is very remarkable. Even in the midst of a migmatite area, where all siliceous rocks have been thoroughly mixed or assimilated with the granite magma, the limestones are generally quite free from granitic injections, and are intersected only by rectilinear pegmatitic dikes. Moreover, the limestone seems to have protected the adjoining wall-rock, which is commonly a leptite. By reason of this preserving action, limestone masses surrounded by narrow layers of leptite or gneiss are common within many of the areas of granites or granitic migmatites. The southern portion of the island of Kimito affords good examples of this phenomenon, but it is quite usual over the whole region of southwestern Finland.

The pegmatites.

Pegmatite dikes occur frequently in most parts of the leptite belt, cutting the various schists and also, though less commonly, the oligoclase-granite. They are believed to be secretions from the microcline-granites, the reasons for this hypothesis being as follows:

1. The pegmatites occur most abundantly near the borders of the leptite area at no great distance from the great microcline-granite masses. In the inner part of the leptite-belt, where it is broadest, i. e. west of the northern part of Lake Määrijärvi, no pegmatites whatever were observed.

2. Where pegmatites occur in the microcline-granites they do so either as dikes with sharp boundaries, or as masses of irregular outline which show a gradual transition from pegmatite into normal granites.

3. At the junction of the microcline-granites and the crystalline schists pegmatite dikes cut the boundary line. Hence they can not be older than the microcline-granites.

4. In large dikes within the leptite area pegmatites grade into even-grained microcline-granites.

On a smaller scale, pegmatites, similar in composition and structure to the other pegmatites, are associeted with the oligoclase-granites in such a way that it is evident that they belong genetically to the latter group of granites.

The pegmatites are equally distributed throughout the leptite area; they are particularly well developed in the eastern and western ends of the belt, i. e. around lake Orijärvi and on the island of Kimito. In these areas they contain rare minerals and are more coarsely crystalline than elsewhere.

As a treatise by the present writer on the pegmatites from Kimito is in the course of preparation, only a brief summary need here be given. [1]

The chief constituents of the pegmatites are q u a r t z, m i c r o c l i n e - p e r t h i t e, a l b i t e - o l i g o c l a s e, b i o t i t e and m u s c o v i t e. The two first-named minerals predominate, and the total composition of the pegmatites is probably not very different from that of the microcline granites.

The distribution of the accessory minerals is interesting as showing distinctly, how different elements may be unequally concentrated although all have probably been derived from the same magma. The following minerals have been observed:

B e r y l has been found abundantly at the pegmatite quarry near Paavo, Orijärvi. Some crystals measured more than one meter in length. Large masses are also found at Rosendal in Kimito. In smaller proportions, beryl is the commonest and most universally distributed accessory of the coarsely crystalline pegmatites of the area.

T o u r m a l i n e occurs commonly as black crystals in almost all pegmatites on the eastern part of the island of Kimito, but elsewhere it is extremely rare. The element boron seems to have been concentrated in this region.

T o p a z in turbid crystals was found at Mattkärr in Kimito. Here also t r i p l i t e, a fluorine-bearing ferro-mangano phosphate, is abundant. A p a t i t e in megascopical crystals was found in a pegmatite at Nyäng, near Skogsböle. At other localities no fluorine-bearing pegmatite minerals were observed. Phosphorus also seems to be concentrated in this same region. Of the phosphates t r i p h y l i n e also occurs at Skogsböle. As noted above, the phosphorus is usually accompanied by manganese. A particular manganese-mineral, an intensely blue-coloured, fine-crystalline m a n g a n e s e-m u s c o v i t e, containing 2.30 % MnO, was found at Mattkärr.

[1] Mäkinen (op. cit.) has studied the feldspars from the quarries of Paavo and Kuusmiilu near Orijärvi.

T a p i o l i t e (skogsbölite) occurs at Skogsböle in Kimito and in several neighbouring localities. Another tantaliferous mineral, i x i o n o l i t e, is found at Rosendal in the same region. Thus the western part of the island of Kimito may be designated as a tantalum-bearing area. In the Orijärvi field, c o l u m b i t e is found at Kuusmiilu.

I x i o n o l i t e is a tantalate containing tin. C a s s i t e r i t e was found at Brant in Kimito, near Brödtorp in Pojo, and traces of it were found in a pegmatite dike north-east of the Orijärvi mine. Thus tin seems to occur sporadically here and there in the pegmatites and shows no tendency to concentrate in any particular region.

G a h n i t e was found in pegmatite near Träskböle in Perniö.[1]

M o l y b d e n i t e was observed at Nyäng in Kimito. A r s e n o p y r i t e occurs in small amounts in a pegmatite dike north-east of the Orijärvi mine. Other sulphide minerals were met with in pegmatites in the vicinity of Träskböle.

C o r d i e r i t e and its pseudomorphs are common accessories. Well formed crystals showing the faces (010, (110), (130) and (001) occur at Puurolampi near Orijärvi and at Nyäng in Kimito. They have been entirely altered into micaceous minerals. Red g a r n e t is common. Fibrous s i l l i m a n i t e was found at many localities in Kimito.

It is a noteworthy fact that almost all dikes containing pegmatite minerals proper, such as tantalates, phosphates, cassiterite, beryl, topaz, etc. occur in femane rocks, either in the amphibolites or in the gabbros. In the whole area there is only the pegmatite at Kuusmiilu near Orijärvi, which cuts the oligoclase-granite, that forms an exception to this rule. Furthermore the pegmatites, in general, show a more typical pegmatitic habit when they intersect femane rocks. [2] In leptites, granites and other salane rocks the pegmatitic character of the dikes is marked rather by their irregular and nonhomogeneous structure than by the coarseness of the grain.

In the typical pegmatites, quartz and feldspar have either crystallized together as g r a p h i c f e l d s p a r, which occurs abundantly in the numerous pegmatite dikes near Skogsböle, or have crystallized separately as enormous individuals. This exceptional power of crys-

[1] P. Eskola, »An Occurrence of Gahnite in Pegmatite near Träskböle in Perniö, Finland», *G. F. F.* **36**, page 25, 1914.

[2] Such a correspondence between the pegmatites and their country-rocks was recently stated also in the pegmatites of Sweden by H. E. Johansson. *G. F. F.* **36**, p. 123. 1914.

tallization gives the pegmatite magma a capacity for differentiation, sufficient to form rock-masses composed of only one mineral. In the most usual cases only quartz was left to crystallize alone as the latest mineral separating from the final residuum of the magma, and is found forming the middle part of the dike supported by sahlbands which consist of feldspar and mica with only small amounts of quartz. Sometimes, however, minerals other than quartz

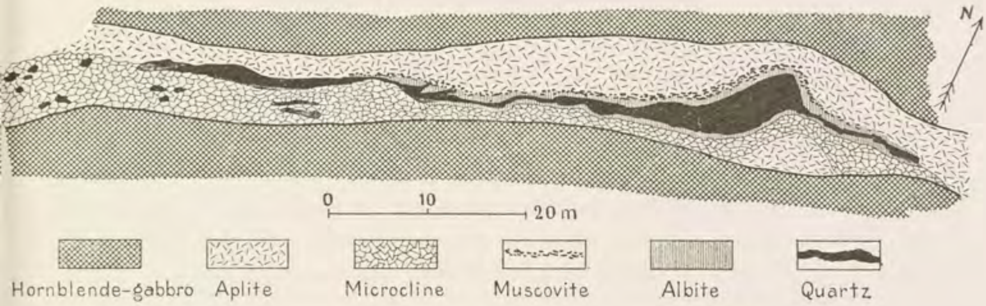

Fig 6. Sketch-map of the pegmatite dike near Rosendal, Kimito.

have crystallized separately. As an excellent example of perfect differentiation by successive separation of crystals in a definite order, a sketch-map, representing the pegmatite dike near Rosendal in Kimito is given (fig. 6). The middle part of the dike consists as usual of pure quartz, but otherwise the dike is unsymmetrically formed. Each mineral occurs in an almost pure form. The ixionolite is found most abundantly in the muscovitic and albitic zones. At the boundary between the latter and the quartz zone, beryl occurs in groups of short prisms, sometimes more than 100 kg in weight.

The oligoclase-granite.

Definition.

In this group we include granitic rocks which occur as large batholiths within the leptite areas, and are usually bounded on all sides by rocks of the leptite series. The name was chosen because the rocks of this group regularly contain soda in excess of potash and have plagioclase always in excess of microcline. The plagioclase ranges from albite-oligoclase to oligoclase-andesine.

Fig. 7. View over the northern shore of Määrijärvi, taken from the southern shore near Rahnola. The area of the Orijärvi granite rises abruptly from the basin which is underlain by the leptite series.

The oligoclase-granites of our leptite area belong to that series of igneous rocks which forms one of the most important groups of rocks of southern Finland and which was distinguished by Wiik and termed by him the o l i g o c l a s e - g n e i s s - g r a n i t e s. This name reminds us that these rocks are almost invariably highly metamorphic. In the present paper, the prefix g n e i s s is omitted partly for the sake of brevity, but more especially because many of the rocks which belong geologically to the group under consideration are not distinctly foliated. It is true that these oligoclase-granites not infrequently pass into potassic types rich in microcline, but gradual transitions and an invariable metamorphic structure prove these to belong geologically to the oligoclase-granites. Such varieties also are quite subordinate, and, unlike the microcline granites discussed above, the predominance of plagioclase is the feature most characteristic of these rocks.

Within the leptite area of southwestern Finland the oligoclase-granites occur in several areas which, though isolated or nearly isolated from each other at the earth's actual surface, are probably connected at greater depths.

The Orijärvi batholith.

We shall begin the study of this massive with a rock-analysis which may be taken as representative of the composition of the rocks which form a considerable part of the area.

For this purpose a specimen taken from the rocky hillocks west of Salmi, i. e. from the central part of the granite mass, was chosen. The chemical analysis was made by the writer with the results quoted in table II.

Table II.

	%	Mol. prop.	Mol. %	Norm		Mode	
SiO_2	71.36	1.189	77.5	Q	32.46 %	Quartz	36.1
Al_2O_3	13.31	.130	8.6	Or	13.34 »	Albite	30.4
Fe_2O_3	0.99	.006	0.4	Ab	30.39 »	Anorthite	5.3
FeO	3.36	.047	3.1	An	13.34 »	Microcline	9.0
MnO	0.10	.001	—		Σ sal 89.53 »	Epidote	
MgO	0.87	.022	1.4	Di	0.00 »	Zoisite	3.7
CaO	2.85	.051	3.3	Hy	$MgSiO_3$ 2.20 »	Orthite	
Na_2O	3.58	.058	3.8		$FeSiO_3$ 5.02 »	Biotite	7.4
K_2O	2.26	.024	1.6	Ap	0.34 »	Hornblende	4.7
TiO_2	0.34	.004	0.3	Il	0.61 »	Magnetite	1.5
P_2O_5	0.21	.001	—	Mt	1.39 »	Ilmenite	0.2
H_2O +	0.45	—	—		Σ fem 9.56 »	Titanite	0.4
H_2O —	0.25	—	—			Apatite	0.2
					99.09 »		98.9
						Al_2O_3 in excess	0.7
							99.6
	99.93	—	100.0		—		—

Yellowstonose near lassenose.

Osann's system:	s	A	C	F	n	a	c	f	k
	76.8	5.5	3.3	5.6	8.5	7.5	4.5	8.0	1.7

The percentages of hornblende, apatite, titanite, epidote minerals and iron ores were determined geometrically. For the calculation of the other constituents, hornblende was, in accordance with analyses of granite-hornblendes, assumed to contain 11 % CaO and 7 % Al_2O_3, and the epidote-minerals to be composed according to the formula $Ca_2Al_2Al(OH)(SiO_4)_3$. The titanium dioxide not needed for titanite was calculated as ilmenite, observed as a relic in the leucoxene-groups. The residual iron ores were regarded as magnetite, to which all Fe_2O_3 must be allotted. All residual (Fe, Mg, Mn)O was assumed to be present in the biotite, whose percentage was calculated on the basis of these figures according to the formula $(H,K)_2(Mg,Fe)_2Al_2(SiO_4)_3$. The feldspars were calculated from the residual amounts of CaO, Na_2O and K_2O, and finally the residual silica was considered as quartz. 0.7 % Al_2O_3 remains after the calculation; probably the hornblende is more aluminous than it was supposed to be.

Quartz is the most abundant constituent. It is present in the form of grains, measuring from about 1 to 2.5 mm in diameter, which, however, have been divided in variously arranged fields. The individual parts show serrated outlines and are frequently separated from each other by a finer-grained mass (Mortar-structure). Strain shadows are very distinct, the whole being suggestive of secondary deformations (pl. I, fig. 4). The undulatory extinction follows the rule defined above (p. 33) which the writer believes to be generally valid so far as rocks whose structure is influenced by a deformation in the solid state are concerned. Inclusions with one moveable bubble are common in the quartz.

The plagioclase occurs as idiomorphic crystals of the same dimensions as the quartz. The crystals are euhedral, but they show fringed outlines owing to a granoblastic fine-grained mass, rich in microcline, which recrystallised around them. The crystals, twinned according to Karlsbad, albite and pericline laws, are always very turbid, and the pigment-like products of decomposition are generally large enough to allow of their determination as epidote or zoisite. As a rule, the epidotization is strongest in the middle of the crystal, and a zonal structure is then observed. Some crystals are comparatively little decomposed even in their inner parts. In this case they are more calcic than the turbid grains. Thus it seems evident that the epidote is formed at he expense of anorthite. The maximum extinction angles in the most calcic parts were about 3° or 4°. The refringence, as compared with that of the quartz, was found to be $\gamma_1 = \omega$. This result indicates a composition near $Ab_{82}An_{18}$. In the kernels of the more epidotized grains extinction angles up to

10° were observed, corresponding to $Ab_{87}An_{13}$; the index of refraction was in all cases lower than ω.[1] Towards the margins the plagioclase gradually becomes more albitic, and at the same time, is less decomposed. Near the margins the extinction angles have values as high as 17°. The plagioclase is in these parts a nearly pure albite, which mineral is also present in the fine-grained mass. According to the results of the chemical analysis the mean composition of the modal plagioclase conforms to the formula $Ab_{86}An_{14}$.

The microcline appears only in the newly crystallized granoblastic mass, the largest individuals being only 0.3 mm in diameter. Generally it is typically cross-hatched, but often only the albite twinning is present, with a maximum extinction angle of 20°. Sometimes considerable parts or even whole individuals in the granoblastic mass consist of simple microcline. Albite in perthite-like intergrowth is very common, but irregularly distributed. Not infrequently albite forms over 50 % of the whole, in which case the microcline begins to assume the lath-like habit.

It seems evident that all the microcline now observable is of a metamorphic origin. It is, however, uncertain whether or not potash feldspar was present as original mineral, but the absence of any large grains or groups of grains would seem to favour the latter alternative.

The epidote occurs in two rather sharply different forms, being found (1) as small, mostly xenoblastic grains in the plagioclase, and (2) as euhedral crystals, associated in a very striking manner with the groups of biotite. These crystals show a strong but very variable birefringence; the extinction in prismatic sections ⊥ (010) is straight, but in sections ∥ (010) it makes an angle of about 35° with the trace of the cleavage planes. The epidote itself is colourless, but in the biotite it gives rise to pleochroic halos.

Zoisite is found in close association with the epidote, the two minerals being often found as parts of the same grain.

The euhedral crystals of epidote often contain a rounded kernel which has a composition different from the rest of the crystal and may consist of orthite. It is of a yellow colour and shows an aggregate polarization with low interference-colours.

The invariable association of the epidote minerals with the biotite commonly observed in the oligoclase granites has suggested the following hypothesis: — It being assumed that both epidote and biotite are of secondary origin they may both have been formed by

[1] It must be noted that, owing to the great turbidity of the mineral, the determinations of the refringence are not quite certain in this case.

the breakdown of potash feldspar and the interaction of its products with some mineral containing (Fe,Mg)O and CaO, e. g. amphibole or pyroxene. Objections to this hypothesis may be raised as follows: — firstly the pair biotite + epidote has a composition richer in alumina than that of any presumable mafic mineral + orthoclase. Secondly the proportion of epidote to biotite is inconstant, and in some slides the one and in some the other of the these minerals is in excess. In any case the secondary, i. e. metamorphic origin of these minerals is not open to doubt, and there remains only the possibility that the crystallized epidote was also formed at the decomposition of anorthite. The concentration of the epidote in the biotitic groups may perhaps be understood as a consequence of the fact that primarily formed crystals of orthite, accompanying the mafic minerals, would serve as centres of crystallization for the epidote.

B i o t i t e is the chief constituent of groups containing most of the coloured minerals. It shows the colours and absorption: $\mathfrak{a}$ = pale brown $<$ $\mathfrak{b}$ = $\mathfrak{c}$ = brown, nearly opaque. The biotite is to some slight extent altered to a green chloritic substance.

The h o r n b l e n d e accompanies biotite and epidote, the three minerals being the chief constituents of the small dark patches. The hornblende occurs as small prismatic crystals, which are euhedral in the zone (110). Its pleochroism is: $\mathfrak{a}$ = pale brownish yellow $<$ $\mathfrak{b}$ = dark brownish green $<$ $\mathfrak{c}$ = dark bluish green. On the whole, the colours are very intense. The mean index of refraction, determined by the immersion method,[1] is:

$$\beta_{Na} = 1.688.$$

This value, which is higher than those of most hornblendes hitherto determined, is in accordance with the considerable prevalence of ferrous oxide over magnesia, the molecular ratio being FeO:MgO = 2.1 : 1.

Most of the black opaque grains seen under the microscope are irregularly formed and are not very small. They were believed to consist of m a g n e t i t e: only occasionally they are surrounded by very narrow zones of leucoxene. There are also small grains and skeleton-like groups of i l m e n i t e, intimately associated with leucoxene. In some of these a lamellar structure is developed. Even

[1] This as well as all the other determinations of the refractive indices by the immersion method were made strictly in accordance with the directions of F. E. Wright, (»The Methods of Petrographic-microscopic Research», Washington, 1911, pages 87—88 and 95—98). The present writer made a few experiments to determine the accuracy of this method. The errors never exceeded ± 0.002, and in most cases they varied within ± 0.001.

when occurring in the interstices of the ore mineral, this t i t a n i t e appears as crystal grains which show a faint pleochroism with pale brown colours. Frequently it forms larger but anhedral crystals, with a minute residual grain of ilmenite remaining in their kernel. Other individuals have a euhedral crystalline form, and are therefore probably of primary origin. A comparative study of several rock slides from different batholiths of the oligoclase-granite showed that original titanite is most abundant in those varieties which contain the highest percentage of anorthite in the plagioclase.

Fig. 8. Oligoclase-granite, west of Salmi, Orijärvi, Kisko. Autotypy from a hand-specimen in natural size.

A p a t i t e occurs as minute rounded prisms and shows crystalline forms towards all the other constituents. This idiomorphism must be explained by the fact that the apatite was the first mineral to crystallize from the original magma and has remained in its original form unaffected by the metamorphism.

Megascopically the analyzed specimen has a reddish grey colour, the red tinge being due to the pigmentation of the larger crystals of plagioclase. Generally the colour of the oligoclase-granites varies between a grey and red, the actual tint being controled by the variations in the colour of the plagioclase. The quartz is generally light smoky grey.

Megascopically the structure is even-grained, and the texture of medium grain (fig. 8). On a closer examination it is seen that the cleavage-planes of feldspar are larger than the average grain, but even these are only a few mm in diameter. On the whole, the most characteristic feature of this rock is the granular habit, and the rock is really finer in grain than it appears to be at first sight. The fine-grained aggregates of dark minerals determine spots some mm in diameter, separated each from other by the quartz-feldspar mass, which spotting causes the rock to look still coarser when seen from a distance. In spite of this highly metamorphic structure, no evidence of foliation or of shearing is noticeable either in hand-specimens or in the field in the rock on the western part of the batholith. In the fine-grained porphyritic contact-varieties only a foliation is present here, and parallel to the boundaries. The foliation at such localities is brought about by the flattening of the quartz-phenocrysts and where there is no contact-facies, as on the coast of Lake Määrijärvi near the cottage of Kolkko, the rock is massive, right up to the boundary.

The gneissose oligoclase-granite in the eastern part of the Orijärvi batholith.

Going eastward and crossing the sound, which joins lakes Orijärvi and Määrijärvi, a foliation gradually becomes noticeable in the inner part of the batholith as well as near the boundaries, and at the eastern end of Lake Orijärvi the parallel structure is so distinct that the term gneiss-granite would be fully justifiable for this special variety. The increase of foliation of the rock towards the East of the district covered by map II is shown by the elongation of its dark inclusions, which will be described later on.

Under the microscope the cause of the well developed foliation is seen in the parallel arrangement of the biotite as well as in the flattening of all the other constituents. Hornblende is typically absent, and the rock is composed of quartz, plagioclase, microcline, biotite, epidote, iron ores and apatite.

The q u a r t z crystals always show lenticular or almost disc-shaped forms. Strain shadows are very noticeable, and conform to the usual rule that the »waves» are $\perp$ axis c. The flattened crystals have no definite crystallographic arrangement and the direction of the shadows is therefore quite variable.

The p l a g i o c l a s e is an oligoclase with small extinction angles in sections $\perp$ (010). It is fresher and shows less evidence of decomposition than does the oligoclase of the non-foliated varieties. It does, however, show very marked traces of mechanical deformation, and has developed the bended lamellae and granulation, which are characteristic of deformed rocks. In comparing this rock with the type described above, the mechanical origin of its granulation is evident. No hornfelsic ground-mass is present. Deformations are frequent both in the individuals which form the »mortar» and in the larger individuals which show serrated outlines. Well preserved kernels of primarily idiomorphic crystals of plagioclase have been also observed.

The microcline occurs also as larger crystals, probably of primary origin, though they, too, are mechanically deformed. Perthitic albite is abundant.

The distinctly gneissose appearance of the rock, however, is chiefly due to the parallel arrangement of the biotite. The structure is identical with that of the non-foliated type, insomuch as most of the mica is concentrated in small groups, but these groups have been so flattened that they now appear as scale-like lenticles. The bending of the scales around the larger grains of quartz etc. gives further proof that the present arrangement of the mica is due to mechanical factors. Epidote with zoisite and orthite, hidden in the biotite-groups, show euhedral crystalline forms which are uninfluenced by the stress.

As the microcline is present only in small proportion, it is probable that the bulk composition of the rock is similar to that of the analyzed specimen from the hills west of Salmi. The absence of hornblende, due to a slight excess of Al_2O_3 or, in other words, to the absence of femic lime, implies no considerable difference in composition. With the exception of the contact-types of the western boundary-zone the different parts of the Orijärvi batholith are fairly uniform in composition.

Inclusions or patches with sharp contacts are common in the Orijärvi granite. Primary aplitic dikes are not rare; they will be described below.

The batholiths southwest of Lake Määrijärvi.

Various types of the oligoclase-granite.

As is evident from a microscopical examination the rocks indicated as »oligoclase-granites» over extensive areas of map I have a composition and structure very nearly similar to those of the Orijärvi granite. A repetition of the description is needless and in what follows we shall only mention those features in which there are notable departures from the type described.

The composition of the Orijärvi granite seems to represent approximately the mean composition of the rocks of all the oligoclase-granite areas and the other rocks seem to show progressive differentiation of the magma: On the one side there are types richer in potash and poorer in lime and ferro-magnesium compounds, and on the other, types in which rocks with more femane composition have differentiated in which the amount of silica and alkalies and especially of potash has been diminished. As the Orijärvi type is unusually rich in free silica, even richer in fact than are the more potassic microcline-granites, the chemical composition of the former can not by any means be regarded as an arithmetical average of those of the extreme types. The differentiation of the more femane part in the magma did not stop with the formation of granites rich in plagioclase. Continued further it has given rise successively to such rocks as quartz-diorites, diorites, gabbros and also some extreme types of peridotitic character. The salfemane rocks, especially, form large portions of the area.

The types of granites richest in potash differ mineralogically from the Orijärvi granite only in that in them the microcline is more abundant. Like the ordinary types they may or may not contain hornblende. Where this mineral is not present, the biotite is usually accompanied by muscovite. If the rock has not been granulated, the microcline usually occurs as large cross-hatched individuals; in other cases there are granoblastic groups consisting only of this mineral.

As no quantitative analyses of the types rich in microcline have been made, the relative proportions of potash and soda cannot be determined. In any case, the percentage of the potash feldspar is probably never so much as 50 % of the whole amount of the feldspars, so that the composition always shows more resemblance to the oligoclase-granites than to the microcline-granites.

The composition of the plagioclase varies from $Ab_{90}An_{10}$ to $Ab_{80}An_{20}$. The varieties free from hornblende regularly have a more calcic plagioclase than such as contain it, which fact shows that this difference in the mineralogical composition is controled by a variation in the amount of the alumina and not by that of the lime.

The most important localities of the microcline-bearing oligoclase-granite are on the shores and small islands at the entrance to Lahdenperä bay in the southern part of Lake Määrijärvi, at the narrow part of the large Iso Kiskojärvi batholith northwest of the lake of the same name, and finally in the northern part of the batholith southwest of Vihiniemi mine near the station of Koski. In the last-named locality the rock is of an intense red colour and comparatively rich in microcline. In structure, it closely resembles the Orijärvi granite, and like that rock is generally hornblende-bearing. Towards the South it passes laterally into the ordinary reddish grey or grey oligoclase-granite.

The granodiorite southeast of Lake Iso Kiskojärvi.

The examples of oligoclase-granite which show the beginnings of differentiation in the femane direction have more calcic plagioclases and a greater quantity of hornblende than the ordinary types. At the same time the amount of titanite usually increases. A specimen from the southeast shore of Lake Iso Kiskojärvi may be taken as an example.

Megascopically this rock is reddish grey, somewhat darker in colour than the ordinary type. It is composed of plagioclase, quartz, hornblende, biotite, microcline, titanite, epidote (besides zoisite and orthite), magnetite and apatite, the order of the minerals being that of their relative abundance.

The structure of this specimen has been but little affected by metamorphic agencies, and many of its original structures are therefore preserved. Thus the plagioclase has been but slightly altered into muscovite (not zoisite) and shows a well developed zonal structure of primary origin. In the kernels the extinction angle in sections $\perp$ (010) and (001) varies from about $+ 15°$ to $+ 23°$, whilst the borders give values between $+ 4°$ and $+ 11°$. The refringence in the shells as compared with quartz is $\omega > \alpha_1$; $\varepsilon > \gamma_1$; $\gamma_1 > \omega$. According to these results the composition of the plagioclase varies from $Ab_{76}An_{24}$ to $Ab_{58}An_{42}$.

Quartz is present in not much lesser quantity than plagioclase.

The hornblende is of the common green type showing $\mathfrak{a}$ = pale yellow $<$ $\mathfrak{b}$ = green = $\mathfrak{c}$ = grass green. $c : \mathfrak{c} = 21°$; the optical character is negative with an axial dispersion of $\varrho > v$. This mineral is xenomorphic towards the plagioclase but idiomorphic towards the biotite. Magnetite in comparatively large crystals forms inclusions, which give a wery characteristic appearance to the hornblende, is abundant and occurs only in the hornblende crystals.

The biotite, present in much smaller quantity than the hornblende, is paler than the average granite-biotite. The axial colours for $\mathfrak{b}$ and $\mathfrak{c}$ are greenish brown. Inclusions of euhedral epidote, often with a kernel of orthite are as characteristic of the biotite as the magnetite is of the hornblende.

Microcline appears only as a product of secondary crystallization and is intergrown with abundant perthite-like albite.

Titanite is more abundant than in the ordinary oligoclase-granite and is evidently of primary origin. It builds euhedral crystals of the characteristic envelope-form. It often shows a polysynthetic twinning. The colours are cocoa brown, and the formula of absorption is the usual $\mathfrak{a} > \mathfrak{b} = \mathfrak{c}$. The optic axial angle, measured with a Klein's lens, was found to be:

$$2\,E = +\,52^\circ.$$

The axial dispersion is $\varrho > v$.

A p a t i t e is also abundant and occurs in comparatively large crystals.

The mineralogical composition indicates that this rock must be comparatively rich in lime and soda, whilst at the same time the amount of free silica is considerable. Probably the most appropriate name for this rock would be g r a n o d i o r i t e.

Quartz-diorites east of Lake Iso Kiskojärvi.

In map II, northeast of Uustorppa near Lake Iso Kiskojärvi, an area of homogeneous rocks has been designated as »intermediate rocks». The rocks of the main part of this area and also those which occur further eastwards very closely resemble the rock described above. Plagioclase, with sharply marked zonal structure and main composition approximately $Ab_{70}An_{30}$, and quartz are the felsic minerals, hornblende and biotite containing most of the femic molecules of the rock. Cocoa brown titanite, in abundance, is a characteristic accessory. In specimens from these localities not one grain of microcline was found. The biotite, however, is present in such quantites that the rock probably contains some 1 % or 1.5 % K_2O. Quartz is considerably less in amount than in the rocks described above, so that in this respect the rock from the East of Lake Iso Kiskojärvi is a true intermediate rock between the granites and the diorites.

These intermediate rocks show, mineralogically and structurally, many analogies with the t o n a l i t e s from Riesenfern, which were made known through the classical description of Becke. The characters of the zonally built plagioclase especially seem to have been originally similar to those of the plagioclase of the tonalites. In the rock from Uustorppa the kernels of the plagioclases are usually altered to epidote and zoisite, the outer and more albitic part being less altered. Some grains, however, show a kernel less anorthitic and less altered than one of the zones surrounding it. The inner border of the most anorthitic zone is most altered and turbid. The outer shell again may consist of the same mixture as the kernel. No such delicate structures as are described by Becke can be seen, but it must be remembered that the rock now under consideration has undergone a metamorphism, and that by this metamorphism many of the primary differences of the plagioclase may have been eliminated.

The structure of the oligo-clase-granites.

In its structure as in its composition, the Orijärvi granite is midway between the extreme varieties. Some specimens show the primary structures well preserwed while others are more completely metamorphosed and have lost all their original features.

Fairly well preserved original structures are seen in the granites east of Lake Iso Kiskojärvi. Megascopically, cleavage-planes of feldspar are visible up to 5 mm in diameter. A specimen from Uustorppa, whose chemical composition is probably nearly identical with that of the Orijärvi granite, and which is composed of the same minerals as that granite, shows an unaltered plagioclase with extinction angles in sections $\perp$ (010) and (001) varying from almost 0° to +13°, corresponding to mixtures from $Ab_{80}An_{20}$ to $Ab_{70}An_{30}$. Many crystals are zonally built, but in others the composition varies more irregularly, and the mineral, when seen between crossed nicols, seems spotted. The epidote minerals are much less abundant than in the Orijärvi granite.

The Uustorppa rock also shows a kind of mortar structure, but there are circumstances which prove that the granulation has been effected neither by a metamorphic re-crystallization nor by mechanical crushing in the solid state, but that it is of protoclastic origin. In it the fine-grained mass which fills up the interspaces between the larger crystals of plagioclase and quartz, shows features which are characteristic of a consolidation structure, and the sequence of crystallization can be determined. The small crystals of plagioclase are fairly idiomorphic, and they also show a zonal structure. The quartz, however, shows ordinary strain shadows, and mechanical deformations may also be seen in the plagioclase.

Still more distinct primary structures were seen in the rock from the southern shore of Lake Iso Kiskojärvi described above as a granodiorite. In this rock the larger grains of quartz show none of the distinct strain shadows, which would prove that secondary mechanical stress had acted upon the rock in the solid state (cf. page 33). The plagioclase, moreover, does not show any bended lamellae or any signs of crushing, even though the larger grains have often been parted into different individuals, which have been pulled apart to considerable distance from each other and have had their original conformation considerably disturbed. All these phenomena may be attributed to the results of movements of the magma before its entire solidification.

This comparatively non-metamorphosed example of the oligoclase-granite series is very important as it affords an opportunity for studying the original habit of these rocks. In its structure the rock shows a certain resemblance to the microcline-granites, especially with regard to the phenomena of corrosion which are very striking in this rock also. The order of idiomorphism is as follows: Apatite, titanite, plagioclase, hornblende, biotite, quartz. The boundary-lines between quartz and plagioclase show the same typical, sinuously curved form that is so characteristic of the contact-lines between quartz and microcline in the microcline-granites. Thus the idiomorphism of the plagioclase towards the quartz is much lessened because of the corrosion. In this respect a notable difference exists between these granitic and granodioritic rocks rich in quartz and the quartz-diorites, poor in that mineral, the corrosion being less significant in the latter rocks and the idiomorphism of the plagioclase therefore more pronounced.

In other, no less numerous cases, metamorphism had proceeded farther than in the Orijärvi granite, its final product being a perfectly granoblastic rock. Such rocks may be found on the southeastern and eastern coast of Lake Määrijärvi. A tectonical zone exists here and the rock carries distinct marks of the movements: The foliation is extremely marked and the rock presents an almost schistose appearance. Included fragments of dark salfemane rocks have been flattened into thin plate-like laminated bodies. In many parts of the area, a mylonitic structure has been produced, and the rock which, at first sight, seems to show a dense leptite-like habit, proves on further examination to consist of a characteristic non-homogeneous mixture in which the patchiness of the granites can be traced by the unequal distribution of the dark minerals. Gradual transitions also prove the crushed rock to have been originally medium-grained. Under the microscope the structure shows mechanical deformations. The quartz especially has been flattened into lenticular grains with marked strain shadows. But a far more striking feature of the actual structure of this rock is the distinct tendency towards granoblasticity, which is most pronounced in the plagioclase (oligoclase). The larger crystals have been broken up into grains each with rectilinear boundary-lines and the finest of the granulated mass shows a typical pavement structure. Here, as usual in this district, the latest metamorphism involved the introduction of active chemical reagents and the traces of the earlier mechanical metamorphic processes have been well nigh obliterated.

Another area of perfectly metamorphosed oligoclase-granite is that in the environs of Lake Tuulijärvi in the parish of Tenala. Here the rock shows a not very fine granoblastic structure, closely resembling that of the typical granite-gneiss from eastern Finland or the iron-gneiss from south-western Sweden.

In all the batholiths of oligoclase-granite the boundary types are more perfectly metamorphic than the inner parts. Very often the contact-varieties, when developed as fine-grained and porphyritic rocks, are perfectly granoblastic. Some instances of such contact-rocks will be described in detail.

The boundary-zones of the oligoclase-granite.

The oligoclase-granites often show no peculiar endogeneous contact-phenomena. Included fragments of the adjacent rocks are common in the boundary-zones, but hardly more frequent than in the inner parts of the rock-masses, and the granite retains its characteristic structure and composition up to the contact-line.

In other cases the oligoclase-granite grades towards its boundaries into more fine-grained types which are either even-grained or more or less distinctly porphyritic. There are a few places where such endogeneous contact-influence can be traced in a typical form. The best examples are found at the western corner of the Orijärvi batholith, as shown in map II, at the western contact of the batholith north of the railway near the station of Skogböle, and at the northern contact of the southernmost batholith, southeast of the station of Koski.

A series of specimens from a section across the endogeneous contact-belt of the Orijärvi batholith were examined quantitatively.

The analysis quoted in table IV was made of a specimen collected from the forest west of the Workmen's Association. It represents the most common type of the contact-facies. The grain is coarse enough to give the rock a granitoid appearance, when viewed with the naked eye, yet the structure is markedly porphyritic with rounded grains of quartz as phenocrysts. The analysis was made by Mr A. Laitakari.

Examined under the microscope this rock appears to be granoblastic, but of a distinct blastoporphyritic character. Plagioclase as well as quartz form phenocrysts, a few mm in diameter, which have been granulated. The individual grains of this plagioclase are somewhat larger in size than those of the ground-mass and show polygonal forms. Twinning according to the Karlsbad law is common and a few lamellae of the albite-type also occur. The extinction in sections $\perp$ (010) is in most cases nearly parallel to the twinning

Table IV.

	%	Mol.prop.	Mol. %	Norm		Mode	
SiO_2	71.69	1.195	77.5	Q	34.14 %	Quartz	38.40 %
Al_2O_3	13.58	.133	8.7	Or	8.90	Plagioclase	
Fe_2O_3	0.62	.004	—	Ab	33.01	$(Ab_{80}An_{20})$	41.85
FeO	3.78	.053	4.0	An	10.84	Biotite	
MnO	0.10	.061	—	Cor	1.53	Muscovite	17.45
MgO	1.16	.029	1.9	Σ sal	88.42	Chlorite	
CaO	2.23	.039	2.5	Hy $MgSiO_3$	2.90	Epidote	1.90
Na_2O	3.90	.063	4.1	Hy $FeSiO_3$	5.94		99.60
K_2O	1.53	.016	1.0	Mt	0.93		
TiO_2	0.34	.004	0.3	Il	0.61		
H_2O	0.67	—	—	Σ fem	10.38		
					98.80		
	99.60		100.0				

Alsbachose.

Osann's system:	s	A	C	F	n	a	c	f	k	T
	77.8	5.1	2.5	5.9	8	7.5	3.5	9	1.88	3.6

lamellae. When comparing the refringence of the plagioclase with that of the quartz, it was found that $\alpha_1 = \omega$; $\gamma_1 < \varepsilon$. This result, corroborated by other observations, determines the mineral as $Ab_{80}An_{20}$. The percentage of the plagioclase was calculated on the assumption that all soda was present in it.

After subtracting the lime needed for the plagioclase, a residue of 0.47 % CaO was left. This amount was supposed to enter into the composition of the epidote, the percentage of which was thus found. The figure arrived at is, however, certainly too high, for small amounts of apatite and calcite have been observed under the microscope. As the percentage of phosphoric pentoxide and carbon dioxide were not determined, the amounts of these constituents could not be calculated. In any case the epidote is much more abundant than either of the minerals mentioned.

Among the mafic minerals biotite is the most abundant. It occurs as isolated scales and also as larger groups. In addition, muscovite and chlorite occur, though only in very small quantities. Therefore silica was allotted to the residual bases in the proportion of the biotite formula. The biotite is dark brown and strongly pleochroic. The grains of epidote and apatite are surrounded by dark halos. As no titanite or ilmenite occurs in the rock, all titanium present must enter into the biotite.

The granulated phenocrysts of quartz show forms suggestive of primary magmatic corrosion. The individual grains of these groups have typical »sutured» joinings. Secondary strain shadows are marked, and they are visible even in the smaller ground-mass individuals, which usually measure from 0.1 to 0.5 mm in diameter. The outlines of the quartz-phenocrysts seem to be but slightly modified by secondary growth, while those of the plagioclase show fringed forms due to the fact that the individuals of the granoblastic ground-mass have partly grown into these larger crystals.

Towards the contact the granite grades into a more distinct porphyritic variety and the ground-mass becomes finer. In certain places the rock closely resembles the blastoporphyritic leptites. A specimen of such a variety, collected a few meters from the contact was analyzed by the writer, with the following results (table V).

Table V.

	%	Mol. prop.	Mol. %	Norm			Mode	
SiO_2	71.50	1.192	76.5	Q		30.90 %	Quartz	31.3 %
Al_2O_3	13.79	.136	8.8	Or		6.67	Potash feldspar	6.2
Fe_2O_3	0.76	.005	—	Ab		38.25	Albite	38.2
FeO	2.07	.029	2.5	An		13.90	Anorthite	10.5
MnO	0.06	.001	—		Σ sal	89.72	Hornblende	10.9
MgO	1.47	.037	2.4	Di	$CaSiO_3$	1.16	Titanite	0.8
CaO	3.54	.063	4.0	Di	$MgSiO_3$	0.60	Biotite	0.5
Na_2O	4.48	.073	4.7	Di	$FeSiO_3$	0.53	Epidote, Zoisite	0.5
K_2O	1.11	.012	0.8	Hy	$MgSiO_3$	3.10		
TiO_2	0.34	.004	0.3	Hy	$FeSiO_3$	2.11	Apatite	0.2
P_2O_5	0.10	.001	—	Mt		1.16		99.1
H_2O+	0.39	—	—	Il		0.61	H_2O	0.5
H_2O-	0.17	—	—	Ap		0.34		99.6
					Σ fem	9.61		
						99.33		
	99.78		100.0					

L a s s e n o s e, near y e l l o w s t o n o s e.

Osann's system:	s	A	C	F	n	a	c	f	k
	76.8	5.5	3.3	5.6	8.5	7.5	4.5	8	1.69

The amounts of the two minor constituents, biotite and epidote (with zoisite) were estimated approximately. The titanite and apatite were calculated from the percentages of TiO_2 and P_2O_5 respectively. As in the former example, the p l a g i o c l a s e was calculated from the percentage of soda, its composition having first been determined by optical methods. Its mode of occurrence as granulated phenocrysts and as a part of the granoblastic ground-mass, is very similar to that of the plagioclase of the former example, except that the grain is finer. The groups are 2 or 3 mm in diameter, the individual grains of the groups from about 0.3 to 0.6 mm, and the ground-mass individuals only about 0.05 mm. The indices of refraction, as compar-

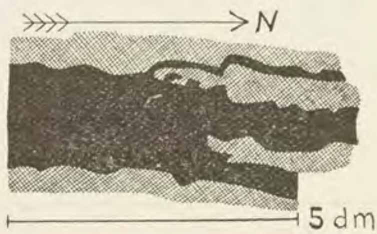

Fig. 9. A part of a felsitic dike in amphibolite near the Workmen's Association house, Orijärvi. Black = felsite.

ed with those of the quartz, are $\alpha_1 < \omega$; $\gamma_1 < \varepsilon$; $\gamma_1 > \omega$; $\beta = \omega$. The last-mentioned value, observed in more than one case, proves the feldspar to have the composition $Ab_{79}An_{21}$.

The remainder comprises the oxides contained in the hornblende and quartz. The hornblende occurs mainly in groups of small prismatic crystals. It shows the colours: $\mathfrak{a}$ = yellowish green < $\mathfrak{b}$ = olive green = $\mathfrak{c}$ = light grass-green. $c : \mathfrak{c} = 17°$. Rounded grains of leucoxene-like titanite occur frequently as inclusions in the hornblende, suggesting by their mode of occurrence that they have separated from the hornblende or from the mineral from which the hornblende had originated.

The b i o t i t e, e p i d o t e and z o i s i t e of this rock in no way differ from the same minerals in the former example.

Felsitic apophyses from the oligoclase-granite.

Where the oligoclase-granite is bounded by amphibolites, these are usually penetrated by felsitic apophyses from the granite. These apophyses are, as a rule, rather narrow dikes, some dm in breadth, and they often form a true network in the amphibolite, e. g. near the house of the Workmen's Association (see fig. 52 page 235). A sketch-map of a part of such a dike (fig. 9) shows their usual habit.

The dikes consist of an aphanitic or very fine-crystalline rock, mostly of a reddish tint. Crystals of hornblende are often distinguishable to the naked eye. In its appearence this rock is exactly like a massive leptite, poor in coloured constituents, and differing from the fine-grained boundary-facies of the oligoclase-granite described above only in the absence of phenocrysts. The junction of these apophyses with the granite mass is exposed southeast of the mine, near the shore of Lake Orijärvi. Here the porphyritic variety grades into the dense leptite-like rock without any sharp contact. The transition, however, is so rapid as to take place within a zone less than 1 cm broad. The impression received is that the dike-rock had consolidated somewhat prior to the final crystallization of the large mass of granite. At this point the writer could not be quite sure that the dikes are really connected with the granite. At the outcrops near the house of the Workmen's Association the nature of these dikes as true apophyses from the granite is made quite clear by the fact that some of the broadest dikes near the chief contact show a transition into the porphyritic contact-modification of the granite.

A specimen of the non-porphyritic dike-rock from the outcrop near the Workmen's Association was analyzed by the writer with the following results (table VI):

Table VI.

	%	Mol. prop.	Mol. %	Norm		Mode	
SiO_2	74.79	1.246	79.4	Q	33.54 %	Quartz	34.1
Al_2O_3	12.33	.121	7.7	Or	2.22	Potash feldspar	2.0
Fe_2O_3	0.37	.003	—	Ab	49.25	Plagioclase ($Ab_{93}An_7$)	53.0
FeO	0.97	.014	1.1	An	6.12	Hornblende	7.3
MnO	0.04	—	—	Σ sal	91.13	Biotite	1.0
MgO	1.23	.031	2.0	Di $CaSiO_3$	1.86	Titanite	0.7
CaO	2.79	.050	3.2	Di $MgSiO_3$	1.30	Calcite	0.7
Na_2O	5.76	.094	6.0	Di $FeSiO_3$	0.40	Epidote	0.5
K_2O	0.42	.004	0.3	Hy $MgSiO_3$	1.80	Apatite	0.2
TiO_2	0.29	.004	0.3	Hy $FeSiO_3$	0.66		99.5
P_2O_5	0.08	.001	—	Ap	0.34	H_2O	0.5
CO_2	0.31	.007	—	Cal	0.70		100.0
H_2O+	0.43	—	—	Mt	0.70		
H_2O-	0.11	—	—	Il	0.46		
				Σ fem	8.22		
	99.92		100.0		99.35		

Mariposose.

Osann's system:	s	A	C	F	n	a	c	f	k
	79.7	6.3	1.5	4.8	9.5	10	2.5	7.5	1.75

The quantities of biotite and epidote present were estimated on the basis of a microscopic examination. The residual amount of potash was supposed to enter into the potash feldspar assumably present as an isomorphous mixture in the plagioclase. Actually no trace of microcline could be detected. The plagioclase forms part of a granoblastic hornfels mass, the grains measuring from 0.02 to 0.1 mm in diameter. Sometimes it shows a few lamellae twinned according to the albite law. The extinction angle was measured in several sections ⊥ (010) and (001). The values obtained varied from 9° to 12°, the average being 11°. All the indices of refraction are considerably lower than those of quartz. These data indicate composition the $Ab_{93}An_7$. The percentage of the plagioclase was calculated from the amount of soda, all of which was assumed to enter into this compound.

The percentages of the other constituents were calculated in the usual way. Of these the hornblende offers some interest. It shows the usual green colours which, however, are paler than in most granite-hornblendes. Another feature, not necessarily connected with the pale colour, is the predominance of magnesia over ferrous oxide as proved by the analysis. In this respect the rock in question differs from normal granites. At many points of the area where felsitic dike-rocks occur they are nearly free from all femic compounds, and it seems probable that this is the original character of the magma which formed these dikes. In field I already arrived at the conclusion that the amphibole of the felsite dikes, often heterogeneously distributed in the rock, is probably a result of assimilation of the country-rock. If this is so, the predominance of magnesia over iron, unusual in granites, can easily be understood, as it is normal for gabbroid rocks.

Apophyses also occur at the western boundary of the Orijärvi batholith, intersecting the amphibolitic rocks. A specimen from the shore of Lake Määrijärvi near the Vanha Pahalahti mine is megascopically red and shows a porphyritic structure. Under the microscope only plagioclase was found as phenocrysts, equidimensional in form and commonly about 1 mm in diameter. The extinction angle in sections ⊥ (010) and (001) varies from 12° to 16°. $\gamma_1 < \omega$. Hence the average composition of this plagioclase may be about $Ab_{94}An_6$. Microcline is present in very small amounts. It is found more especially round the phenocrysts. The ground-mass is chiefly composed of plagioclase and quartz the almost uniform size of the grains being about 0.05 mm in diameter. Trifling amounts of biotite, epidote and calcite occur. This dike-rock is, no doubt, related to those at the eastern side of the batholith. Other dikes which occur further south at the granite boundary, consist of aplites rich in potash feldspar.

In order to give a better view of the variations in the composition of the endogeneous contact-belt, the series of analyses (as mol. %) is given in table VII. (N:o I represents the rock in the inner part of the batholith (page 41), and n:o IV the dike-rock which forms the outermost contact-facies).

Table VII.

	I	II	III	IV
$SiO_2 + TiO_2$	77.7	77.8	76.8	79.7
Al_2O_3	8.7	8.7	8.8	7.7
FeO[1]	3.5	4.0	2.5	1.1
MgO	1.4	1.9	2.4	2.0
CaO	3.3	2.5	4.0	3.2
Na_2O	3.8	4.1	4.7	6.0
K_2O	1.6	1.0	0.8	0.3
	100.0	100.0	100.0	100.0

No doubt the most striking feature is the very regular increase in Na_2O and decrease in K_2O when approaching the margin of the batholith. This is certainly due to a magmatic differentiation. As pointed out above, the felsitic apophyses representing the variety richest in soda, have been solidified at an earlier epoch than the main rock-mass. Thus they must be regarded, from a geological as well as from a chemical point of view, as the outmost contact-facies of the granite, and they certainly have nothing to do with aplites of the usual kind, rich in potash and occurring as dikes in the main granite also.

According to these analyses the contact-facies of the granite is no more fcmane than the main rock, in opposition to what is commonly regarded as a regular endogeneous contact-phenomenon. Further, it seems probable that a considerable part of MgO and FeO present in rocks III and IV has been derived from the country-rock through assimilation. As already mentioned, many of the dike-rocks are poorer in mafic minerals than the specimen analyzed, and the

[1] Total Fe (with Mn) calculated as FeO.

MgO : FeO ratio in the latter is more in accordance with that of the amphibolite than with that of the granites, represented by analyses I and II. Furthermore, rocks III and IV are comparatively richer in lime than the former, and in consequence contain amphibole which is absent in rock II, as the main mafic mineral. We are led to the conclusion that the apophyses from the granite into the amphibolite and also the outmost endogeneous contact-facies of the granite towards the amphibolite are products of differentiation, somewhat enriched in femic compounds through a magmatic assimilation of the more femane country-rock.

Such amphibole-bearing light-coloured rocks, poor in femic compounds, are only found at the boundaries between the granite and the amphibolites. Where gneissic rocks bound the granite, the contact-varieties of the latter are free from amphibole, but very rich in biotite. Such is the rock from the most northwestern corner of the granite mass. A slice of it contained plagioclase, quartz, biotite, apatite and zircon, but no potash feldspar. The composition of the plagioclase varies from $Ab_{85}An_{15}$ to $Ab_{75}An_{25}$, and this mineral sometimes shows a distinct inverse zonal structure. The rock is blastoporphyritic and in all its features resembles the rock represented by the analysis quoted in table IV (p. 54). Compared with the main rock, it shows a slightly higher percentage of iron oxides and magnesia, the mutual ratio between these compounds being constant. The amount of soda also is higher than that of the main rock, while the percentage of lime and potash is smaller.

These granoblastic granite rocks afford a good example of the laws controlling the relations between biotite and hornblende, inferred from many other metamorphic rocks in this area: If lime is in excess of the proportion needed to form anorthite with the alumina present, hornblende is formed, and the potash goes to form microcline. On the other hand, if all lime present can be bound in the anorthite and there is yet alumina in excess, then (Fe,Mg)O enters into the biotite, which is formed at the expense of microcline. If the amount of (Fe,Mg)O is sufficient, all potash goes to form biotite. With an excess of Al_2O_3, no microcline is found even if potash is present in excess of the proportion needed for biotite. The excessive potash then goes to form muscovite. Biotite and muscovite may be found together, and so may biotite and hornblende, but hornblende and muscovite exclude each other. In rocks free from hornblende but with abundant biotite, the plagioclase is often more calcic than in many amphibole- and microcline-bearing rocks.

Diopside (with c : c = 45°) was found in certain dike-rocks near Kolkko (map II), intersecting an amygdaloidal amphibolite and limestone. The presence of this mineral must be ascribed to the fact that the amount of alumina was insufficient to form anorthite with the lime present, and that the femic lime in proportion to (Fe,Mg)O was in excess of what can enter into any hornblende. The excessive lime must have been derived from the country-rock through assimilation, and the diopside probably separated at the crystallization of the magma. But it may be noted that this mineral was constant also during the metamorphism. As there was no source of iron or magnesium, the pyroxene could not be uralitized. Some hornblende is associated with the pyroxene, but no biotite.

Granitic intrusions round the Orijärvi batholith.

Small sill- or vein-shaped masses of grey granites penetrate the rocks of the leptite series within and round the basin of Lake Orijärvi. They are conformable with the general strike, and are usually only a few decimeters broad. Some of the largest masses are indicated on map II. These granitic sills are very variable in their composition.

A specimen of medium-crystalline grey granite from the forest north of the farm of Perheentupa consists of plagioclase and smaller amounts of quartz and biotite. The refractive indices of the plagioclase are lower than those of quartz, and an extinction angle in a section ⊥ (010) and (001) was about — 8°. Hence it must consist of about $Ab_{88}An_{12}$. No potash feldspar was detected.

None of the minerals show any idiomorphism. The structure, however, seems to be nearly primary and not granoblastic.

Another specimen from a narrow band in the same tract contains individuals of microcline, 2 to 5 mm in diameter. Numerous rounded or irregularly formed grains of quartz are included in them. The interstices between these crystals of microcline consist of a mosaic of quartz, biotit eand muscovite. No plagioclase and even no perthitic albite could be detected.

A slice of fine-grained white aplite from the island of Vähäholma (see fig. 39 page 87) also consists of quartz and microcline, with small amounts of micas but no plagioclase.

It seems to be very characteristic of these small intrusions that they have been differentiated into types extremely rich either in soda or potash feldspar. It seems most probable, however, that they are all connected with the oligoclase-granite, as they are conformable with the general strike and do not show that pegmatitic structure which is so characteristic of the apophyses from the microcline-granite.

The chemical nature of the oligoclase-granite and its relations to the other rocks.

The analyses of the Orijärvi granite, compared with those of the microline-granites, show several peculiar characteristic features:

1. Soda is prevalent over potash.
2. The sum of the alkalis is low.
3. Lime is relatively abundant, but less than the soda.
4. Iron oxides and magnesia are abundant.
5. The percentage of silica is somewhat smaller than in the microline-granite, but the amount of free quartz is equal or even more, owing to the smaller proportion of alkalis.

Most of these characters are evident from a comparison of the Osann figures for the representatives of both rock types:

	s	A	C	F	n	k
The Orijärvi granite (p. 41)	77.8	5.5	3.3	5.6	8.5	1.72
The Perniö granite (p. 17)	81.2	7.0	1.2	1.6	3.6	1.76

The value of k does not give any exact idea of the proportion of free quartz. This appears only from the modes:

	Modal quartz
The Orijärvi granite	36.1 %
The Perniö granite	32.2 »

The composition of the Orijärvi granite approaches that of granodiorites. The percentage of lime is, however, lower than in most rocks to which the name granodiorite has been applied. In this respect the oligoclase-granites of the areas in question seem to be very invariable, for the composition of the plagioclase was found to be nearly the same throughout the greatest parts of the different batholiths. True granodiorites are also found (p. 49), but they undoubtedly occupy only inconsiderable parts of the rock-masses.

It cannot be decided at present to what extent the above-mentioned characteristics are of a general nature in the older Archaean granites of the Sveco-Fennian range. The granites of Upland, Sweden, which in their mode of occurrence and structure are exceedingly similar to our oligoclase-granites, have also much in common with these as regards their chemical nature. For comparison we quote analyses of two examples:

I. Sala granite, Sala, Westmanland, Sweden. Analyst R. Mauzelius.[1]

II. Upsala granite, Upsala, Sweden. Analyst R. Mauzelius.[2]

III. Orijärvi granite (p. 41).

	I.	II.	III.
SiO_2	75.72 %	69.95 %	71.36 %
Al_2O_3	10.77 »	12.30 »	13.52 »
Fe_2O_3	1.71 »	2.09 »	0.99 »
FeO	1.62 »	2.72 »	3.36 »
MnO	0.13 »	0.13 »	0.10 »
MgO	1 12 »	2.03 »	0.87 »
CaO	2.14 »	4.26 »	2.85 »
BaO	0.06 »	0.06 »	—
Na_2O	1.75 »	1.99 »	3.58 »
K_2O	3.86 »	3.13 »	2.26 »
TiO_2	0.26 »	0.42 »	0.34 »
P_2O_5	0.08 »	0.12 »	0.21 »
H_2O	0.98 »	0.91 »	0.70 »
	100.20 %	100.11 %	99.93 %

The low percentages of alkalis and the large amounts of (Fe,Mg)O and free silica are common to all, but the proportions of soda, potash and lime are different. The Upsala granites can be classed with granodiorites. Their plagioclase also is more calcic than what I have found in the oligoclase-granites, up to Ab_1An_1.[3]

The contacts of the oligoclase-granite.

Wherever oligoclase-granites or other rocks of the same group are in contact with the microcline-granites, the microcline-granite is found to be of a later origin. Such is the case in the parish of Kimito where oligoclase-granites, grading into quartz-diorites, occur as a belt between the leptites and the microcline-granite. Apophyses from the latter consist of pegmatitic varieties. Along the boundary the microcline-granite forms a contact-zone composed of a grey even-grained granite of the Hiittis type. This modification passes gradually into the coarse porphyritic Perniö granite.

The Orijärvi batholith is bounded by the microcline-granite to the East, and the contact-line is well exposed near the farm of Leila. Near the contact the microcline-granite is heterogenous.

[1] P. J. Holmquist, »Studien über die Granite von Sweden», Bull. *Geol. Inst. Univ. of Upsala* VII, p. 264, 1906.

[2] Ibid. p. 266.

[3] Ibid. p. 182.

Some parts consist of aplitic modifications poor in dark minerals, other contain much biotite and resemble contorted and highly assimilated (nebulitic) fragments. Pegmatitic modifications also occur.

The contact is sharp, but apophyses from the younger rock are frequent. They also consist of aplitic or pegmatitic modifications. Penetrating further into the oligoclase-granite the apophyses become less numerous and assume a markedly pegmatitic character.

The fragments of oligoclase-granite enclosed in the microcline-granite at the boundary are somewhat contorted and gneissoid, but the characteristic texture of the rock is recognizable, so that there can be no question of any refusion (anatexis) in the sense defined by Sederholm. Some ten meters from the contact, the older rock assumes its normal habit. It is just in the absence of any anatectic features that the large masses of infracrustal rocks within the leptite belt differ from most other occurrences of related rocks in the Southwest of Finland. Generally such older granites have been largely assimilated by the microline-granite magma.

Tigerstedt was not aware of these very conspicuous contact-phenomena, and could not therefore recognize the different age of both granites, but believed that there was a gradual transition from the greyish Orijärvi granite to the red granite in the East. Sustschinsky did not see any difference whatever between these two granites. [1]

The contacts between the oligoclase-granites and leptitic rocks sometimes are masked, and no sharp limits can be found. Such is the case near the Orijärvi mine (cf. p. 218). It must be assumed that the sharp boundary line has been obliterated by later metamorphism. As a rule it has been well preserved, and sharp-edged fragments of the leptite are enclosed in the granite.

Dark inclusions in the oligoclase-granite.

Dark inclusions are very characteristic of the oligoclase-granites. As indicated on maps I and II, the occurrence of inclusions is not limitted to any particular portions of the batholiths, and the areas where no inclusions are found, are near the boundaries as well as in the central parts of the granite masses. But whereas the inclusions occur-

[1] Sustschinsky (41, p. 424) writes with regard to the Orijärvi granite as follows: »Der Granit südlich von Orijärvi und auch an den Gruben Haukia, Malmberg u. a. ist ein gewöhnlicher postbottnischer Granit». It may be noted that, so far as southwestern Finland is concerned, the term »post-Bothnian» is practically synonymous with »microline-granite».

ring in the boundary-zones consist of rocks which can be recognized as some of the rocks adjacent to the granite, at a distance from the contacts they are of a more uniform character and in many cases show a structure and composition not to be found in the rocks which bound the granite. Thus the Orijärvi granite contains, near its contacts, inclusions of leptites, amygdaloidal amphibolites etc., whilst in its central parts there are only dioritic inclusions.

The dioritic inclusions in the central parts have irregular forms with somewhat rounded edges. They are equidimensional in those parts where the granite has a massive structure, but where the granite is foliated, the inclusions assume lenticular shapes, arranged parallel to the foliation.

Fig. 10. Inclusions in the oligoclase-granite. West shore of Lake Simjärvi, Pojo.

In the batholith south of Lake Määrijärvi, dark inclusions are very frequent. Fig. 10 shows the usual forms and also gives an idea of the frequency of the fragments, which is nearly constant in large areas.

An inclusion in the granite from Uustorppa at the northeastern shore of Lake Kiskojärvi was found to be composed of plagioclase, hornblende, biotite, quartz, titanite, microcline, apatite and black iron ore, the quantitative proportions being indicated by the above order.

The plagioclase which forms about a half of the whole is zonally built, its composition varying from $Ab_{62}An_{38}$ to $Ab_{75}An_{25}$. The main plagioclase was estimated at about $Ab_{70}An_{30}$.

The hornblende is of the common green type. The biotite shows the greenish brown colours common in this mineral in the dioritic rocks of the area.

The quartz forms about 10 % of the rock, the microcline much less. Both these minerals fill up interspaces between the other minerals.

Titanite is euhedral and of that cocoa brown type described above (p. 49).

This example is very instructive, as here the effects of later metamorphism have been so slight that a structure of consolidation is quite evident. The plagioclase is idiomorphic both towards hornblende and biotite; towards the quartz it shows corroded sinuous outlines. Some crystals of plagioclase are somewhat larger in size than the average grain, about 0.2 or 0.3 mm in diameter.

Dark inclusions of the same character as those under consideration are well known in Fenno-Scandian geological literature. Högbom first described the »basic segregations in the Upsala granite».[1] This petrologist was by his careful studies led to the conclusion that the dioritic inclusions found so plentiful in the older Archaean granites (»Urgraniter») of Sweden must be regarded as »concretionary formations, basic segregations, from a granitic magma». During later years a few notes on this subject were made by several writers. In 1910, O. Tenow and C. Benedicks [2] experimented in applying a physico-chemical diagram to explain the origin of the dark inclusions, supposing them to have been originally fragments from adjacent older rocks. This theory is summarized in a later paper [3] by the same authors, as follows:

»Ein Bruchstück, das in einen genügend heissen Schmelzfluss hineingekommen ist, wird — — in allgemeinen teilweise geschmolzen: ringsum bildet sich eine Schmelzzone, darin sind Partikeln aus der festen Phase vorhanden. Im allgemeinen müssen diese Partikeln eine gewisse Tendez haben mit einander und mit dem noch ungeschmolzenen Kern des Bruchstückes zusammenzubacken (kapillare Anziehung); dadurch ensteht oft eine Anreicherung der festen Phase um den Kern herum.» In this case the solid phase is represented by the mafic minerals, biotite and hornblende, which had originally been present in excess of a eutecticum, remolten earlier.

The writers distinguish four types of inclusions representing different stages of re-fusion and assimilation:

1. In which only the outmost shell of the fragment has been influenced.

2. In which a kernel of the fragment has remained unfused surrounded by a femane concretionary zone and outside this by a paler-coloured eutectic zone.

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[1] *G. F. F.* **10**, p. 218, 1888, and **15**, p. 251, 1893.

[2] Ibid. **32**, p. 1506, 1910.

[3] Ibid. **33**, p. 33, 1911.

3. In which there is no kernel, but otherwise as 2.

4. In which the eutectic zone has resorbed part of the concretionary zone and its composition has become identical once more with that of the surrounding magma.

5. In which the femane concretion has begun to spread, having been partly dissolved in the magma.

The theory of Benedicks and Tenow, applied to the inclusions of the Orijärvi granite, has many advantages over the older hypothesis of Högbom, but fails to give full elucidation of certain points. The following circumstances seem to me to be of importance as throwing light on the origin of the dark inclusions found in the inner parts of the batholiths:

1. Over wide areas the dark inclusions are evenly scattered, throughout the mass.

2. The form of the individual patches, though somewhat rounded, is of the irregular type which is characteristic of rock-fragments, and is unlike that of true concretions due to crystallization about certain centres.

3. The size of the individual inclusions is variable and seems to follow no regular law.

4. The contacts with the country-rock are sharp but not rectilinear. The individual crystals have grown across the boundary between two kinds of rock as though there had been no difference in the conditions of crystallization.

5. As a rule no zonal or otherwise regular arrangement of the minerals can be observed. Most of the inclusions thus belong to type 4 of Benedicks and Tenow.

6. The composition of the inclusions seems to vary between the same limits as that of the gabbro-dioritic rocks bounding the oligoclase-granite.

7. The structure of the inclusions when they have escaped later metamorphism, is a true structure of consolidation. At one single outcrop various inclusions have been found which represent the same structural varieties that are present in the gabbro-diorite area.

This last observation proves that the inclusions cannot be caught-up fragments only altered by contact-metamorphism. The invariability of their composition is, also, hard to reconcile with a hypothesis which explains the inclusions as fragments of the adjacent country-rocks, as these, (e. g. around the Orijärvi batholith) have a very variable composition.

Only two possible explanations remain: (1) Either the inclusions have consolidated in situ, or (2) they have broken away from an igneous rock consolidated immediately before the crystallization of the granite, but having had nearly the same temperature as the granite magma by which therefore they were not attached. The former eventuality would include the explanation given by Benedicks and Tenow. But the absence of any zonal structure does not favour this theory. For if the mode of origin is the one outlined by these authors, type 4 represents a definite stage in the series of gradual transitions between types 3 and 5, and, of course, in its typical form it should be very rare. On the contrary, types 3 and 5 are of a rare occurrence.

It may also be noted that in the inclusions as well as in the massive diorites the plagioclase is decidedly the most idiomorphic of the major constituents. Most probably it was in excess of the eutectic proportion, and not the mafic minerals, as presumed by the theory of Benedicks and Tenow.

With regard to the difficulties attached to the above theory the second possible hypothesis concerning the mode of origin of these inclusions seems worthy of some consideration: Diorites and gabbros were differentiated from the magma of the great batholiths and consolidated at an earlier time than did the granites themselves. Such femane rocks might also have separated at the hanging walls of the batholiths, which are now eroded away. Fragments of newly consolidated diorites were loosened and sank down in the magma because of their greater specific gravity. Under such conditions the fragments had nearly the same temperature as the magma, and could not be refused completely. As they are somewhat rounded, a partial refusion may have taken place, but owing to a sinking movement, the molten parts could be assimilated with the magma.

An analogous phenomenon was observed by the writer in a rock-wall near Suurkylä, Hogland, Finnish Bay. The sub-Jotnian quartz-porphyry of Hogland contains here sharp-edged fragments of a somewhat darker variety of the same rock. Quite similar fragments were also observed in the metamorphic quartz-porphyry (blastoporphyritic leptite, p. 135) near Lapinkylä in Kisko, in the area under consideration. In this case the darker colour was found, on microscopical examination, to be due to a larger amount of biotite than what is present in the main rock. No refusion or any influence whatever from the surrounding rock could be inferred. Perhaps the dioritic inclusions in the oligoclase-granite need no other explanation than that which seems natural in this case, viz. that fragments from the first consolidated portions have sunk in the still fluid magma.

Diorite and gabbro.

Masses of dioritic and gabbroid rocks are associated with many batholiths of oligoclase-granite. In some parts of the area they have been metamorphosed into amphibolites, and resemble those derived from supercrustal rocks. In other parts their original structures have been preserved, so that they can be classed as gabbros or diorites.

Diorites east of Malmberg in Kisko.

In the range of the Orijärvi batholith such rocks are insignificant. They occur only at the southeastern and eastern boundary of this mass. The rock is of an amphibolitic type, but there is some evidence that it belongs to the infracrustal series, as will be shown later on (p. 75).

Gabbro southwest of Skogsböle in Kimito.

In the western part of the leptite belt a large mass of infracrustal amphibolitic and gabbroid rocks occur south of Skogsböle in the parish of Kimito. The rocks afford examples of different degrees of metamorphism, most pronounced at the margins of the area and diminishing towards the centre. About one kilometer southwest of the Skogsböle farm, a specimen of gabbro was collected which shows characters observed in no other parts of the area. It is a perfectly nonmetamorphic gabbro, composed of bytownite (about $Ab_{15}An_{85}$), diallage, orthorhombic pyroxene, hornblende ($c : \mathfrak{c} = 11°$; $\mathfrak{a}$ = pale greenish brown $< \mathfrak{b} \leqslant \mathfrak{c}$ = greyish brown), apatite and magnetite. The order of idiomorphism is: Apatite, magnetite, rhombic pyroxene, diallage, bytownite, hornblende.

I have not revised my field-observations in this locality after having examined the rock-slide just described and thus I cannot with any confidence refute the suggestion that this rock may be a post-Archaean intrusive in the Archaean gabbro. But no such conclusion could be drawn from anything hitherto known to me. Examples of perfectly non-metamorphosed gabbros and diabases in the Archaean, among their metamorphic derivates, are known from other parts of Finland.

In other areas within the leptite-belt feebly metamorphic gabbros are common, but they are hornblende-gabbros containing neither pyroxenes nor olivine. Sometimes the hornblende seems to be entirely of primary origin. In this case the original mineralogical composition is the same as that produced by metamorphism, and then structural changes are also inconsiderable. More often, however, the hornblende must be partly or entirely of secondary origin. In such cases the structure shows more traces of a metamorphic influence: the minerals have been granulated, and much recrystallized plagioclase occurs. When hornblende is formed at the expense of ferro-magnesium pyroxene or olivine and diopsidic pyroxene, the anorthite also takes part in the reactions, and the newly formed plagioclase is more albitic than the original (cf. p. 129). On the other hand, the formation of hornblende is always possible when the original mafic minerals of a gabbro are such as those just mentioned. Where the original minerals nevertheless remained, the reason for their preservation can only be that the rock never came under the influence of metamorphic agencies.

Diorites and gabbros southwest of Määrijärvi in Kisko.

The largest mass of gabbro-dioritic rocks of the area in question occurs southwest of Lake Määrijärvi. Here the batholith of oligoclase-granite is divided into two portions by a mass of these rocks which stretches from the southern coast of Lake Määrijärvi in a southerly direction and forms almost a semicircle, whose central portion, about 5 km in diameter, is made up of granite. The breadth of the gabbro-diorite belt is from 3 to 4 km. This bow-like arrangement is apparently an essential primary feature in the structure of this batholith, for the lenticular inclusions of diorite in the granites and granitic Schlieren in the diorite are all conformable with it.

The rocks are partly diorites, partly gabbros. Transitions are frequent. Alternating dioritic and gabbroid belts, and zones of various structure, are arranged parallel to the general strike of the rocks.

Hornblende-gabbro from Sepänlampi, Hauksuo, Kisko.

A specimen of hornblende-gabbro from the shore of a little lake named Sepänlampi near the village of Hauksuo was subjected to a quantitative examination. The chemical analysis, made by the writer, gave the following results (table XIII).

The mode given above was determined by the Rosiwal method. All the minerals are somewhat altered. Thus the hornblende shows an incipient alteration into pale green chlorite with a comparatively high birefringence ($\gamma - \alpha > 0.015$) and noticeable biaxiality. The unaltered hornblende is impregnated with a black pigmentary substance, arranged in zones, so that in some individuals the middle is turbid, and in others there are turbid zones near the margins. A characteristic product of the alteration of the feldspars is a micaceous mineral with a high birefringence, probably muscovite.

Table VIII.

	%	Mol. prop.	Mol. %	Norm		Mode	
SiO_2	50.56	0.843	53.9	Q	0.48	Quartz	4.3
Al_2O_3	16.38	.161	10.5	Or	5.56	Plagioclase	37.0
Fe_2O_3	1.78	.011		Ab	18.86	Hornblende	54.5
FeO	6.67	.093	7.6	An	31.97	Biotite	1.8
MnO	0.16	.002		Σ sal	56.87	Ilmenite }	1.7
MgO	7.70	.193	12.6	Di { $CaSiO_3$	7.31	Magnetite }	
CaO	10.06	.180	10.7	Di { $MgSiO_3$	4.60	Apatite	0.5
Na_2O	2.25	.036	2.3	Di { $FeSiO_3$	2.24	Pyrite	0.2
K_2O	0.90	.010	0.7	Hy { $MgSiO_3$	14.80		100.0
TiO_2	0.96	.012	0.8	Hy { $FeSiO_3$	7.26		
P_2O_5	0.12	.001	—	Mt	2.55		
Cr_2O_3	0.06	—	—	Il	1.82		
S	0.10	.003	—	Ap	0.34		
H_2O+	2.06	—	—	Σ fem	40.92		
H_2O-	0.23	—	—		97.79		
	99.99		100.0				

Auvergnose.

Osann's system:	s	A	C	F	n	a	c	f	k
	54.7	3.0	7.5	23.3	7.7	1	4	14	0.96

There are two different kinds of plagioclase in this rock, one appearing in the manner of porphyritic individuals and having a marked zonal structure, and another, which forms the ground-mass, without this zonal structure, more fine-grained and less altered than the former. It may be noted that the difference is not so much in the size of the individuals as in the characteristics just mentioned, and it is probable that the former is the original igneous feldspar and the latter of a secondary origin. The refractive indices in all plagioclases are higher than those of quartz. In the zonal crystals the kernels show, in sections ⊥ (010), a maximum extinction angle of 45° which indicates a feldspar of the composition $Ab_{27}An_{73}$, and the shells 29°, corresponding to $Ab_{47}An_{53}$. In the homogeneous individuals the maximum extinction angle found was 24° ($Ab_{56}An_{44}$) a section ⊥ (010) and (001) gave +25° ($Ab_{55}An_{45}$). Since the composition is so variable, its average could be only roughly estimated at about $Ab_{50}An_{50}$. The biotite was assumed to posses the composition of that mineral from quartz-monzonite, Walkerville Station, Butte, Mont.[1] Magnetite and ilmenite were assumed to be present in equal amounts. After the subtraction of all the compounds of the above mode with the exception of hornblende, we obtain the remainder quoted in table IX.

Table IX.

	Remainder	Hornblende recalculated to 100 %	Hornblende from dacite. Cabo de Gata
SiO_2	25.0 %	46.3	45.76
TiO_2	0.6	1.4	1.43
Al_2O_3	5.6	9.6	8.80
Fe_2O_3	1.1	2.3	5.32
FeO	5.6	11.6	11.23
MnO	0.16	0.3	0.57
MgO	7.5	15.6	14.08
CaO	6.0	12.5	10.62
Na_2O	0.1	0.2	1.39
K_2O	0.7	—	0.26
Cr_2O_3	0.1	0.2	—
H_2O	2.3	—	0.05
	54.76	100.0	100.31

This remainder includes all the potash contained in the rock except that which enters into the biotite. This residual potash was calculated as orthoclase and muscovite, the percentage of the latter having been estimated at 1 %. These potash-bearing components and the water having been subtracted, the remainder was considered as hornblende. It includes the pigmentary and chloritic substances whose amount, however, is too slight to cause any considerable error in the result. The figures obtained agree fairly well with the analyses of hornblendes from igneous rocks comparatively rich in MgO and CaO, as is shown by a comparison with the analysis of hornblende from dacite, Cabo de Gata, Spain.[2]

[1] »Quant. Classific.», table XIV, c.

[2] H. Rosenbusch, »El. Gest.» 2 Aufl. p. 298.

The optical properties also resemble those of a very usual type of common hornblende: a = $\mathfrak{a}$, b = $\mathfrak{b}$, c : $\mathfrak{c}$ = 17°; absorption colours $\mathfrak{a}$ pale brownish green < $\mathfrak{b}$ = olive green < $\mathfrak{c}$ = bluish green; the mean index of refraction determined by the immersion method:

$$\beta_{Na} = 1{,}639.$$

Twinning parallel to (100) is common.

The biotite is of a common brown type and nearly uniaxial. Black grains of iron ore are abundantly enclosed in this mineral. No pleochroic halos were observed.

In its structure the rock from Sepänlampi displays all the peculiarities of an igneous rock (pl. I, fig. 5). The zonal crystals of plagioclase are most idiomorphic of the main constituents. In fact, they resemble porphyritic individuals, the largest being more than 5 mm in diameter, whilst the average grain is 0.3 mm. They show a marked tendency towards tabular development, which is euhedral where the feldspar comes in contact with quartz.

The idiomorphism of the plagioclase towards hornblende is also very pronounced. In this feature the hornblende-gabbro differs, in a striking manner, from the amphibolites, in which the amphiboles are always idiomorphic owing to recrystallization, or idioblastic, to use the terminology of Becke.

It is evident that the hornblende-gabbro has preserved its original structure. As there is nothing to prove that the hornblende is a product of alteration of pyroxene or of any other mineral we have good reason to believe that the mineral composition is also essentially the same as it was when the rock crystallized from the magma. But a recrystallization seems to be in process. The fine-grained feldspar of the »ground-mass» is probably new-formed, and among this mass small idioblastic grains of hornblende are scattered which are clear in colour and without any inclusions or products of alteration.

Diorite from the northern shore of Lake Iso Kiskojärvi.

The gabbro grades frequently into dioritic and quartz-dioritic rocks. An extensive and somewhat uniform diorite area occurs between Lake Iso Kiskojärvi and Lakes Tyrsäjärvet.

The dioritic rock from the northern shore of Lake Iso Kiskojärvi is composed of plagioclase, hornblende, quartz, microcline, epidote and zoisite, titanite, apatite. Biotite is absent, and in its stead small amounts of potash feldspar are present, filling up the spaces between the other minerals. Microcline-twinning is often visible.

The plagioclase of this quartz-diorite occurs in two generations: (1) larger idiomorphic crystals which show a zonal structure and (2) smaller polygonal individual grains. The maximum extinction angle in the latter in sections ⊥ (010) was 18°, corresponding to about $Ab_{65}An_{35}$. Probably this value represents nearly the average composition of the granulated plagioclase. The zonal crystals, on the other hand, are very heterogenous. They have almost invariably a kernel consisting of an individual crystal of zoisite or epidote or of a mixture of these minerals. Around this kernel two or three different zones may be observed. An idiomorphic crystal cut || (010) (fig. 11) showed four zones: The outermost shell gave an extinction angle of — 2°, and should therefore contain about 65 % Ab, as does the granulated plagioclase. This zone is also perfectly clear and its outlines are fringed. The next zone showed an extinction angle of — 10°, corresponding to about 57 % Ab. It is broader than the former and limited by rectilinear boundaries. The third zone forming the greatest part of the central portion consists of a labradorite with about 45 % Ab, the extinction angle, somewhat variable at different points, being about — 20°. Two inclusions of zoisite occur in the central part of the crystal, their outlines being partly conformable with the zones. At one point a spot of unaltered plagioclase could be seen. In this spot the extinction angle was — 33°, indicating a decrease in Ab to about 15 %. Thus the zones in which the feldspar has altered to individual crystals of epidote minerals, consisted originally of bytowtnite. The large range of variation — from 15% Ab to 65% Ab — is remarkable, but is quite comprehensible on the assumption that pyroxenes were originally present and that the hornblende was formed from them and from the anorthite constituent of the plagioclase. Thus the plagioclase of secondary growth would be poorer in anorthite than any zone of the original feldspar. The outermost shells of the zonal crystals, which show fringed outlines, belong also to the second generation of the plagioclase.

Fig. 11. A crystal of plagioclase, cut || (010). Quartz-diorite from the north shore of Lake Iso Kiskojärvi, Kisko. Magn. 18 diam.

The hornblende is similar to that from the hornblende-gabbro of Sepänlampi described above. A great part of this mineral has developed as euhedral prisms — a proof that it is of a metamorphic or crystalloblastic origin.

Titanite occurs only as euhedral crystals as in the intermediate rock from the oligoclase-granite area. The quartz and the apatite show no peculiarities.

The traces of metamorphism in this rock are considerable, but nevertheless many original features can still be identified. Thus it may be seen that numerous primary crystals have been broken up in a manner indicating movement in a partially consolidated rock.

In other examples the granulation had proceeded further owing to recrystallization. In numerous cases the structure resembles »mortar structure» induced in a rock by the influence of mechanical stress. Here, however, no traces of any mechanical deformations can be inferred. The granulated portions show a true pavement (»Pflaster») structure, characterized by the rectilinear outlines of the individual grains. If this process of granulation proceeds still further, so as to obliterate even the last traces of the primarily idiomorphic feldspars, the result is an amphibolite not distinguishable from perfectly granoblastic amphibolites derived from supercrustal rocks. In the border-zones of the batholiths the dioritic rocks have actually been so changed. The diorites east and southeast of the Orijärvi batholith are, for the most part, exactly like the amphibolites occurring north of the same batholith and their true nature would scarcely be recognizable, if they were not associated with granitic Schlieren in the same manner as the less metamorphic diorites and gabbros southwest of Lake Määrijärvi.

In other examples there are more albitic plagioclases and greater amounts of quartz. It may be said positively that all degrees of transition between the gabbro and the oligoclase-granite exist in this area.

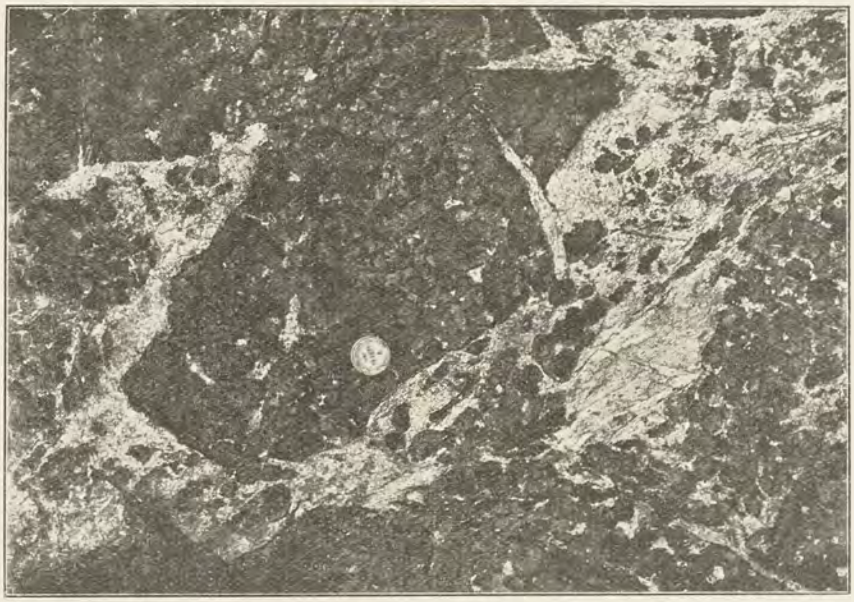
Hornblendite.

Numerous small areas within the gabbro-diorite are made up of dark rocks composed mainly of hornblende. One of these is located at the eastern shore of Lake Iso Myllylampi near the contact between the gabbro and the oligoclase-granite. It is a breccia-like mixture of coarse-grained hornblendite and fine-grained or medium-grained aplite, which forms veins in the hornblendite. The aplite, reddish in colour, is composed of oligoclase and quartz and is similar to those described below (p. 81). A few large crystals of hornblende are enclosed in the aplite, and in the hornblendite-rock red plagioclase occurs as xenomorphic grains filling up the interspaces between the crystals of hornblende.

The h o r n b l e n d e has developed into large individual crystals. It is more brownish in colour than the hornblende of the gabbro or granite. The scheme of pleochroism is: $\mathfrak{a}$ light brown $<$ $\mathfrak{b}$ = greenish brown = $\mathfrak{c}$ = brownish green. $c : \mathfrak{c} = 16°$ to $18°$. Its optical character is negative and the axial angle not far from 90°.

Titanite and iron ore occur as inclusions in the hornblende. The former is found as rounded subhedral crystals and the ore as irregular grains. Both kinds of inclusions are surrounded by narrow pleochroic halos, in which the colours are the same as in the main part of the mineral, only darker.

The plagioclase is mainly altered to epidote and zoisite; calcite is also present. In an almost symmetrical section of the feldspar an extinction angle of 14° was observed. All indices of refraction being considerably higher than those of the Canada balsam, the mineral contains at least 20 % An.



Fip. 12. Hornblendite and oligoclase-aplite. $^1/_5$ nat. s. Near Iso Myllylampi, Kisko.

The euhedral habit adopted by the hornblende makes it evident that this mineral is of a primary origin. Metamorphic features cannot be traced in the hornblendite, although the intruding »younger» aplite has only faint traces of its original structure preserved.

This occurrence is a good example of differentiation on a miniature scale. (The rock covers an area of about 30 × 50 m.) A magma, whose composition was probably the same as that of a gabbro [1], has

[1] It may be pointed out, that this same magma which actually crystallized with much hornblende and a small proportion andesine and quartz, could also give diopside + bronzite besides a more anorthitic plagioclase and no quartz.

provided the material for a monomineralic rock, i. e. hornblendite, which was solidified earlier, and a plagioclase-quartz-rock. [1] It seems evident that the splitting of the magma is here only due to the earlier crystallization of the hornblende.

Near Uustorppa near Lake Iso Kiskojärvi a small mass of hornblendite occurs in the oligoclase-granite, and not in the gabbro. Here also the hornblende is idiomorphic and apparently an original constituent of the rock. The plagioclase, forming the cement between the crystals of hornblende, shows in sections ⊥ (010) a maximum extinction angle of 10°, corresponding to $Ab_{73}An_{27}$. Thus the hornblenditic rock here is nearly similar to the one just described.

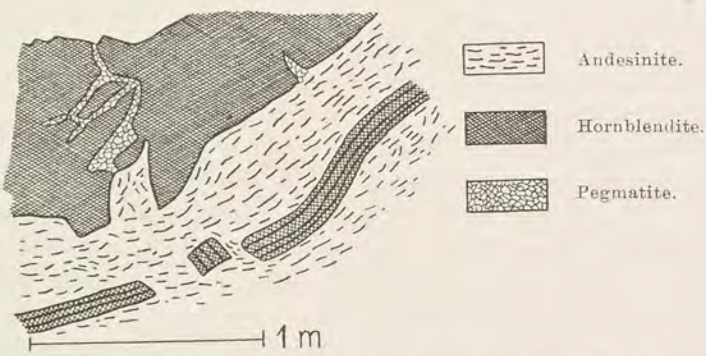


Fig. 13. Differentiated bands of hornblendite in andesinite. The hornblendite had been solidified earlier and had been broken up into fragments before the crystallization of the andesinite. Heinäsuo, Pojo.

In the neighbourhood of a morass named Heinäsuo, northwest of Lake Osmajärvi, the gabbro is free from granitic bands; there is nevertheless a banded structure in which the lighter and darker portions alternate. At this same place there is an occurrence of titaniferous magnetite, taking the form of a few schlieric bands and more lens-shaped bodies, only one or two meters in thickness. Besides the bands of magnetite, there are other bands which consist of hornblendite, and both are bounded by a rock almost devoid of dark minerals, and composed mainly of andesine. The bands of hornblendite often assume a marked fragmentary character, being intersected by the andesinitic rock, and they are often broken into pieces which have been upturned so that their parallel structure has

The occurrence of iron ore near Heinäsuo.

[1] Vide: J. H. L. Vogt, »Über anchi-monomineralische und anchi-eutectische Eruptivgesteine». *Vidensk. Selsk. Skrifter. I. Math.-Naturv. Kl.* 1908, N:o 10.

taken up position perpendicular to the general strike (fig. 13). Pegmatitic secretions composed of abundant quartz, microcline, plagioclase and hornblende occur in the hornblendite.

The iron ore is mainly composed of magnetite and hornblende in varying proportions. Beside these minerals only small quantities of epidote were observed. The structure is probably perfectly granoblastic, since neither of the chief minerals has any primary idiomorphism. The smaller individual crystals of hornblende often show an idioblastic development towards the larger grains which seem to be original individuals.

The hornblende is rather pale green and possesses the usual properties of this mineral.

A portion of the magnetite was separated mechanically with a horse-shoe magnet and by washing the powder with water. A quantitative determination of titanium dioxide contained in the ore-mineral gave 0.75 %.

The hornblendite is composed almost exclusively of a green hornblende similar to the one found in the iron ore. Only small amounts of magnetite and quartz were found as accessories. The structure is granoblastic like that of the iron ore. Unlike the coarse-grained primary hornblendites, this rock is fine-grained, the diameters of the grains varying from 0.1 to 1 mm.

The hornblende shows a positive optical character at a large axial angle and dispersion $\varrho > v$. The colours are $\mathfrak{a}$ = greenish yellow $<$ $\mathfrak{b}$ = olive green $\leqq$ $\mathfrak{c}$ = bluish green. $c : \mathfrak{c} = 16—18°$.

The quantitative mineral composition of a specimen of the andesinite, collected from one of the light bands, was estimated geometrically with the following result.

Andesine	85.1 %
Quartz	5.3 »
Magnetite	4.9 »
Hornblende	3.6 »
Biotite	0.5 »
Apatite	0.6 »
	100.0 %

From this mode the chemical composition of the rock was calculated on the basis of the following data.

The plagioclase is homogeneous in composition. A crystal cut exactly ⊥ (010) and (001) gave an extinction angle of + 18°.

The refringence compared with quartz is $\alpha_1 > \omega$, $\gamma_1 > \varepsilon$, $\alpha_1 < \varepsilon$; and the composition therefore is not far from $Ab_{65}An_{35}$, which formula was used for thec alculation.

The hornblende shows properties similar to those of the hornblende in the hornblendite. The calculated composition of the hornblende from the gabbro near Sepänlampi (page 72) was used.

The result of the calculation is as follows:

SiO_2	57.8	%
Al_2O_3	22.3	»
Fe_2O_3	3.5	»
FeO	2.0	»
MgO	0.6	»
CaO	7.0	»
Na_2O	6.4	»
K_2O	0.1	»
TiO_2	trace	
P_2O_5	0.3	»
	100.0	%

Subrang Persodic, rang Alkalicalcic of Canadare.

Such a composition seems to be quite unknown among igneous rocks, and that subrang with which this rock classes itself has no examples in Washington's tables. The true labradorites are mostly much richer in lime (8—12 % CaO).

The structure of this »andesinite» is chiefly granoblastic, but it shows also distinct primary features. Among the mosaic of untwinned plagioclase grains, about 0.1 mm in diameter, there are larger grains, up to 1.5 mm in diameter, well twinned according to the Karlsbad, albite and pericline laws.

Although the actual structure of the hornblendite is mainly granoblastic, there are remnants of hornblende which is are probably of a primary origin. It may therefore be assumed that the rock originally was also composed of hornblende, and that the process of differentiation is analogous to that described above. A composition which is nearly identical with that of the gabbro from Sepänlampi could be attained by the addition of about equal amounts of andesinite and hornblendite and a smaller amount of magnetite. The non-differentiated rock surrounding the ore-field of Heinäsuo on all sides has also a mineral composition which could be obtained by a simple addition of the differentiated rocks. This gabbro passes gradually into the andesinite and at the same time the darker fragment-like bands become accentuated. Hence it is evident, that the differentiation took place only in the gabbro magma. It is noteworthy that in this case two nearly monomineralic rocks (besides the small quantity of iron ore) were produced as a result of the differentiation.

The hornblendite was the first portion to be separated. When all the femic oxides have been separated from a gabbroid magma in the form of hornblende, the feldspathic residue must be richer in albite than the plagioclase of that pyroxene-bearing gabbro which has the composition of the original magma. When, on the other hand, the first portion to separate from the magma had the composition of a peridotite, rich in magnesia, the remaining portion would crystallize as a typical anorthosite.

The peculiar composition of the salane rocks associated with the hornblendites owes to the fact that they represent that portion of the gabbroid magma which was left after the crystallization of the hornblende.

Granitic and aplitic bands and dikes in gabbro and diorite.

The gabbros and diorites are commonly associated with light bands and Schlieren, conformable with the general strike of the rocks. Three types of such secretions occur:

Granitic bands. (1) The rocks themselves are composed of different banded masses, of which some approach the oligoclase-granite in composition. These granitic bands are rich in hornblende or biotite, and distinctly foliated parallel to their strike. At some places the granitic portions make up more than a half of the whole rock mass. As a rule, their manner of occurrence makes it evident that they have consolidated later than the darker portions. But in many cases it is quite impossible to say with certainty whether the granite is younger or older than the diorite. The contacts show gradual transitions.

The granitic bands are variable in composition, in just such a manner as the oligoclase-granites in the large areas. As they differ from these oligoclase-granites in no way except that they are usually very distinctly foliated they need no special description.

The oligoclase-aplite. (2) Other bands are poorer in biotite and hornblende than the average oligoclase-granite. When quite devoid of dark minerals, they show a type of white aplitic bands, very common in the area southwest of Lake Määrijärvi. This type is illustrated in fig. 14. They show sharp contacts and resemble newer intrusive veins. They are, however, only short and posses wedge-like ends. The bands of this type are conformable with the general strike. They are characteristically composed of oligoclase and quartz without or with very little potash feldspar.

A specimen from one of the bands shown in fig. 14 was found to be composed of quartz, plagioclase, small amounts of microcline and chloritized biotite. The p l a g i o c l a s e rarely shows any twinning, and gives extinction angles of only one or two degrees in sections $\perp$ (010). Its refringence is: $\omega > \alpha_1$; $\varepsilon > \gamma_1$; $\gamma_1 > \omega$, and hence the composition might be nearly $Ab_{80}An_{20}$. The quartz, present in approximat-

Fig. 14. Bands of oligoclase-aplite in hornblende-gabbro. Near Iso Myllylampi, Kisko. $^1/_5$ nat. zize.

ely equal amount to the plagioclase, occurs partly in the form of polygonal grains, and partly as lenticular individuals. As the structure is materially granoblastic, no noticeable deformations are observed.

In other specimens only oligoclase, quartz and a little biotite were found, but no potash feldspar.

The microclinea-plite.

(3) A third type of granitic secretions are more like ordinary dikes, for they have sharp boundary walls and often cut the country-rock in directions independent of its strike. These a p l i t i c d i k e s are also short, but are often of a considerable breadth. They are made up of a light-coloured, red or white aplitic granite, composed chiefly of quartz, microcline and albite. Pegmatitic modifications

are sometimes connected with them. Similar dikes may also be found in the oligoclase-granite.

Whereas the aplitic bands are only a modification of the oligoclase-granites and immediately related to them genetically, the dikes of microcline-aplite are of a more independent character. When these two rocks cross, it is the microcline-aplite dikes that cut the bands. While the bands must have consolidated almost contemporaneously with the gabbro and diorite, the dikes are decidedly of a later date. This is well illustrated at the northern contact of the

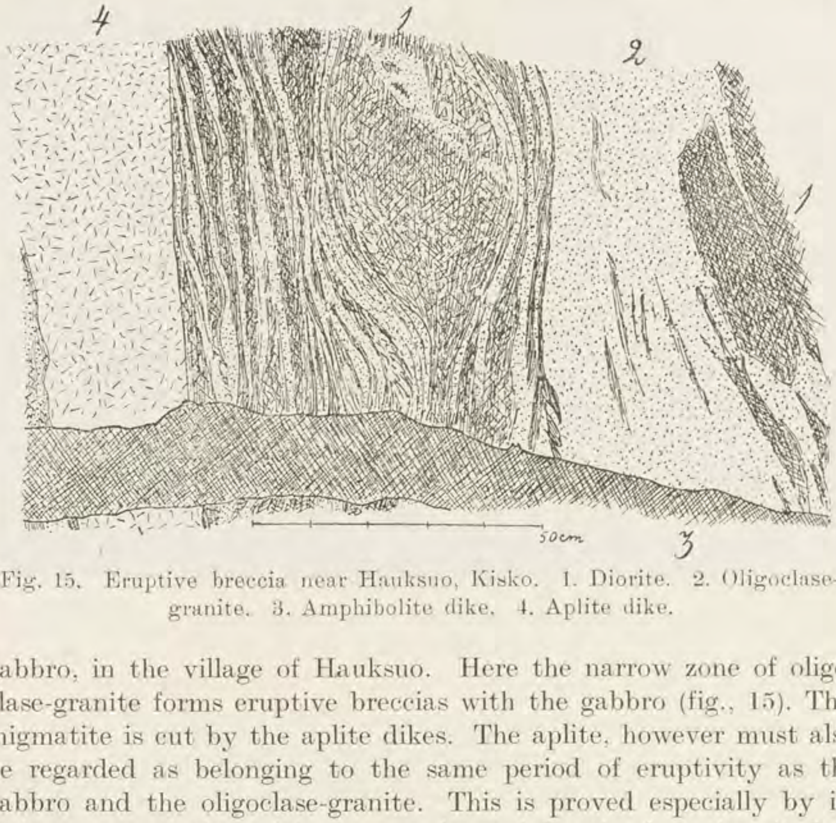


Fig. 15. Eruptive breccia near Hauksuo, Kisko. 1. Diorite. 2. Oligoclase-granite. 3. Amphibolite dike. 4. Aplite dike.

gabbro, in the village of Hauksuo. Here the narrow zone of oligoclase-granite forms eruptive breccias with the gabbro (fig., 15). This migmatite is cut by the aplite dikes. The aplite, however must also be regarded as belonging to the same period of eruptivity as the gabbro and the oligoclase-granite. This is proved especially by its intimate association with these rocks and by the fact that it does not occur in the leptite series at a distance from the gabbro and oligoclase-granite area. Furthermore, the dikes are only »blind veins» and can hardly have come from any great distance. Finally, these dikes of aplite are also cut by dikes of a perfectly granoblastic amphibolite (see fig. 15. This dike-rock is described on page 115). In the younger microcline-granites such dikes were never found.

From the above facts we are led to regard the aplitic dikes as the latest consolidated portions of the same magma from which the oligoclase-granites as well as the gabbros and diorites have differentiated.

A geometrical analysis was made of a specimen from the dike shown in fig. 15. As the minerals are easily determinable and the rock is homogeneous, the figures should give a rather exact idea of the mineral composition of this aplite.

Quartz	48.9	%
Plagioclase	22.9	»
Microcline	20.4	»
Biotite	4.4	»
Magnetite	1.9	»
Epidote	1.5	»
	100.0	%

Besides these minerals single crystals of z i r c o n, t i t a n i t e and o r t h i t e were observed, but their amount is apparently quite insignificant. These minerals will not be considered in the following calculation.

In order to find out the chemical composition of the rock on the basis of this mode, the first step was to determine the composition of the p l a g i o c l a s e. This is zonally built. The kernels are highly altered to zoisite and albite. The maximum extinction angle in sections ⊥ (010) is 18° indicating an almost pure albite, as the refringence is considerably lower than that of quartz. The outer zones also consist of albite. These border-zones are always quite clear and unaltered. But some individuals were found in which the centre also was clear, and in them the extinction angle was different from that of the borders; for example: shell 15°, kernel 1°, the sign being the same in both. The boundary of the zones is rather sharp. Thus we conclude that the composition of the plagioclase varies between Ab and about $Ab_{80}An_{20}$. The altered kernels were assumed to contain all the lime which has actually been taken up by the zoisite. On this assumption, the average plagioclase of this aplite is about $Ab_{85}An_{15}$. Of the minor constituents the biotite may be assumed, without great error, to have the composition of the biotite from the granodiorite of El Capitan, Yosemite Valley, Cal.[1] For the epidote the theoretical composition may be used. The following figures were obtained:

[1] »Quant. Classific.» Table XIV, a.

SiO_2	79.1 %
Al_2O_3	10.3 »
Fe_2O_3	1.5 »
FeO	1.3 »
MgO	0.4 »
CaO	1.1 »
Na_2O	2.3 »
K_2O	3.9 »
H_2O	0.1 »
	100.0 %

Tehamose.

This aplite differs from normal granitic rocks in being remarkably rich in quartz.

Among the chief mineral components the plagioclase shows the highest degree of idiomorphism, and it has sometimes well preserved crystallographic outlines, parallel to the inner zones. Often, however, this mineral shows irregular contours, and quartz as well as microcline is enclosed in it. The quartz and microcline are perfectly xenomorphic and have apparently crystallized simultaneously. As they form the main part of the rock, this has, on the whole, the panallotriomorphic structure (Ramsay), characteristic of aplitic dike rocks.

A parallel arrangement is very distinct, due as much to the elongated forms of the quartz as to the parallellism of the biotite scales. The quartz shows a feebly developed undulatory extinction which resembles that observed in the microcline-granites (cf. page 33), Such undulation is, however, no proof that the rock has suffered mechanical deformation after the consolidation of the magma, nor have any other signs of crushing been observed. The rock is also free from any traces of recrystallized minerals and shows in all respects a true consolidation structure. Hence the parallel arrangement must be regarded only as a consequence of fluctuation during the process of crystallisation, a conclusion which is fairly well supported by the microscopical examination.

The relations between the gabbros and diorites and the oligoclase-granite.

Along the inner boundary of the bow-shaped area of gabbros and diorites these rocks show gradual transition into the oligoclase-granite. Sometimes intermediate rocks occur, which on a small scale seem homogeneous rocks. This is the case on the eastern coast of Lake Iso Kiskojärvi. More often the transition is by way of schlieric bands, the granitic portions growing gradually broader as they approach the granite area. This manner of transition is well illustrated in the rocky region southeast of the lake.

These relations hardly admit of any interpretation other than that the two series of rocks have been differentiated from the same magma. Tigerstedt has previously arrived at this same conclusion. On the whole, the gabbro-dioritic rocks have been concentrated in the peripheral parts of the batholith and consolidated at a somewhat earlier

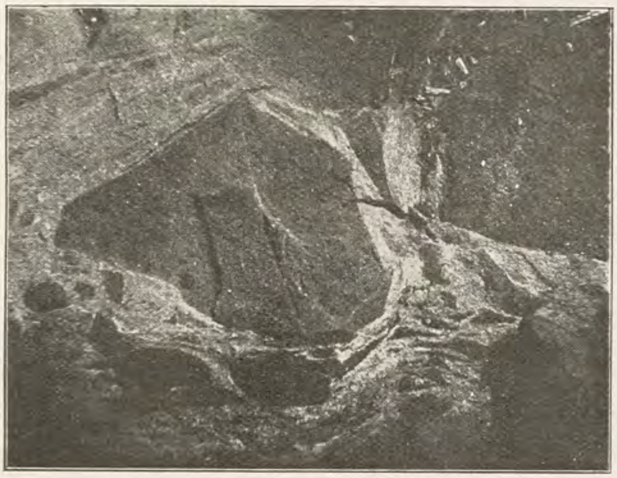


Fig. 16. Eruptive breccia. Fragments of gabbro in oligoclase-granite. Hauksuo, Kisko. $^{1}/_{12}$ nat. size.

time than the rest. There exists, however, a zone of oligoclase-granites also at the outer boundary of the batholith. North of the gabbro-diorite area this zone has developed as a narrow belt bounding the leptite series. Here the granite, in its contact with the gabbro, shows a more decidedly intrusive character, often forming true eruptive breccias (fig. 16; see also fig. 15 on page 82). The granite in this belt is also directly connected with the granite on the inner side of the gabbro-diorite area. Thus the same granite at one side penetrates the diorites as a »younger» rock while on the other side there is a gradual transition from the granite to diorite. This circumstance can be explained as follows.

The consolidation began along the walls of the magma basin, where the more femane portions were first separated and the diorites, gabbros, hornblendites etc. were formed. Some kind of rhythmical crystallization must be assumed to have given rise to the banded structure. When the consolidation of the batholith had proceeded so far that only the inner part of a granitic composition remained in a magmatic state, the outer rock-masses loosened from the walls and granitic magma intruded, an outermost zone of granite being thus formed. At a later period and when the greater part of the granite had crystallized, the aplite dikes originated, intruding also into the eruptive breccias formed of granite and gabbro etc. But even then the eruptive activity had not finally ceased. At a time considerably later, when the former series of rock had already cooled and possibly also the actual section of the lithosphere in this region had been brought nearer the land-surface by the process of erosion, joints were opened and a basaltic magma intruded to form the dikes which became metamorphosed to amphibolite, when the whole leptite series had sunk into the microcline-granite magma.

The hornblende-gabbro from Mäkijärvi in Kisko.

Many massifs of abyssal or hypabyssal rocks of gabbroid composition occur within the area of supercrustal rocks, having probably intruded in the form of laccoliths. Their relations to the large batholiths of granite and gabbro are not clear, owing to their occurrence as isolated masses.

One such mass underlays a well-defined area bounded by metabasaltic amphibolites in the northern portion of the parish of Kisko, north of a little lake named Mäkijärvi. As the rock is conspicuous and shows some interesting petrographical features not met with elsewhere in the area, it was analyzed by the writer. The results of the analysis are quoted in table X.

On account of the intricate mineral composition, the mode of this rock could not be calculated from the analysis, while a peculiar nonhomogeneity in the structure prevented geometrical estimation. The mineral components arranged in the order of decreasing percentage are: Plagioclase, hornblende, biotite, leucoxene, quartz, microcline, apatite, ilmenite, magnetite.

The p l a g i o c l a s e in association with quartz and microcline forms a fine-grained granoblastic mass, but occurs also as larger lath-shaped crystals up to 1 mm in diameter. The latter show a very pronounced zonal structure with gradual transitions between the different zones. They are idiomorphic, especially when bounded by quartz or microcline, and are twinned according to the albite and

Table X.

	A	B	Average	Mol.prop	Mol. %	Norm	
SiO_2	50.87%	50.79%	50.83%	0.847	56.4	Q	2.28 %
Al_2O_3	20.84	20.71	20.78	.204	13.8	Or	8.90
Fe_2O_3	1.33	—	1.33	.008		Ab	20.96
FeO	7.43	—	7.43	.103	8.1	An	41.14
MnO	0.14	—	0.14	.002		Σ sal	73.28
MgO	2.77	2.78	2.77	.070	4.7	Di $CaSiO_3$	3.02
CaO	10.32	10.18	10.25	.183	12.3	Di $MgSiO_3$	1.10
Na_2O	2.50		2.50	.040	2.7	Di $FeSiO_3$	1.98
K_2O	1.51		1.51	.016	1.1	Hy $MgSiO_3$	5.90
TiO_2	1.06		1.06	.014	0.9	Hy $FeSiO_3$	8.71
P_2O_5	0.35		0.35	.003		Ap	1.01
H_2O+	0.74		0.74	—		Il	2.13
H_2O-	0.11		0.11	—		Mt	1.86
						Σ fem	25.71
	99.97		99.80		100.0		98.99

H e s s o s e.

Osann's system:	s	A	C	F	n	a	c	f	k
	57.3	3.8	10.0	15.1	7.0	10.5	7	2.5	0.90

pericline laws. A section $\perp$ (010) and (001) showed extinction angles, in the kernel of + 35°, and, in the outer shell, + 13°. In another section extinction angles of + 34° and + 7° respectively were observed. Hence the composition of this plagioclase varies from $Ab_{33}An_{67}$ to $Ab_{73}An_{27}$. The normative plagioclase which is somewhat more calcic than the average of what is actually present, is $Ab_{35}An_{65}$.

The h o r n b l e n d e is present only as small idioblastic prisms, scattered in the plagioclase or accumulated in groups of a few mm in diameter. It is of the common green type.

The b i o t i t e always occurs in groups of one to three mm in diameter surrounding the l e u c o x e n e (pl. I, fig. 6). Such an association of biotite and leucoxene is the most characteristic feature of this rock. The biotite is not very dark; it shows $\mathfrak{a}$ = pale yellowish brown $<$ $\mathfrak{b} = \mathfrak{c}$ = dark brown. It is formed as minute scales in a subparallel arrangement, and the whole groups are somewhat flattened, giving the rock an indistinct foliated appearance. The leucoxene is formed of a fine-crystalline aggregate, pale brown in colour and of a high birefringence. It shows characteristically a structure pseudomorphous after the ilmenite, which is also present as a relic. These groups can scarcely be explained otherwise than as products of chemical reactions which took place between the original ilmenite, potash feldspar, anorthite, water and some magnesia-bearing mineral, e. g.:

$$FeTiO_3 + KAlSi_3O_8 + CaAl_2Si_2O_8 + H_2O + MgSiO_3 =$$
$$CaTiSiO_5 + H_2KAl_3(SiO_4)_3 \cdot MgFeSiO_4 + SiO_2.$$

Quartz and microcline occur only in the granoblastic fine-grained mass. Black opaque, irregular grains not associated with the leucoxene were regarded as magnetite.

We have here a highly metamorphic rock in which a primary ophitic structure is dimly visible. The rock may have been composed originally of plagioclase, ilmenite and orthorhombic pyroxene, perhaps accompanied by augite. It is chemically related to anorthositic rocks, being at the same time characterized by the prevalence of ferrous oxide over magnesia.

Peridotite.

Peridotitic rocks occur in smaller masses, as a product of differentiation of gabbros and diorites, in several parts of the area under consideration. Only the most extensive of these occurrences have been delineated on map I.

Peridotite occurs as a more isolated and homogeneous massif in the northeastern part of the area covered by map I, north of Lake Pyhälampi in the parish of Suomusjärvi. This massif continues beyond the area of the map and measures more than 4 km from South to North. The greatest part of it is occupied by a fine-grained and non-foliated peridotitic rock with abundant olivine. In some parts, olivine is absent and the rock is then distinctly foliated. This is also the case in such parts where plagioclase is found as a constituent mineral. Towards the South the rock passes gradually into a schistose plagioclase-amphibole-rock which is intersected by frequent veins of red microcline-granite. In the East the peridotite is bounded by a larger area of microcline-granite. The latter intersects the peridotite at the contacts, but it is a striking incident that the granite has not intruded into the inner part of the mass. Only quite near the contacts were a few narrow apophyses of granite observed.

Infrequent veins of quartz are the sole alien bodies within the peridotite mass. In one of them a pit has been made in search of ores. The quartz here contains grains of chalcopyrite, pyrite, pyrrhotite, molybdenite and magnetite, besides crystals of tremolite and pale green apatite. Chrysotile also occurs as narrow veins. The country-rock is schistose and plagioclase-bearing.

An analysis of the peridotite from the northern shore of Lake Pyhälampi was made by the writer. A fine-grained, even-granular variety containing only small quantities of monoclinic pyroxene and no bronzite was chosen. The results are as follows (table XI):

The mode was determined by the Rosiwal method, in several thin sections.

By treatment of the rock powder with hydrochloric acid and diluted sodium hydroxide, 28.65 % were dissolved, while the geo-

Table XI.

	%	Mol. prop.	Mol. %	Norm		Mode	
SiO_2	42.96	.716	42.6	Or	0.56 %	Edenite	66.9 %
Al_2O_3	8.11	.079	4.8	Ab	2.10	Diallage	3.5
Fe_2O_3	3.31	.021		An	20.57	Olivine	15.1
FeO	10.36	.144	11.5	Σ sal	23.23	Serpentine }	
MnO	0.23	.003		Di { $CaSiO_3$	11.02	Chlorite }	14.0
NiO	0.05	.001		Di { $MgSiO_3$	7.80	Magnetite }	
MgO	19.30	.482	29.4	Di { $FeSiO_3$	2.24	Chromite	0.2
CaO	9.65	.171	10.4	Hy { $MgSiO_3$	15.90	Pleonaste	0.2
Na_2O	0.24	.004	0.2	Hy { $FeSiO_3$	4.62	Pyrrhotite	0.1
K_2O	0.11	.001	0.1	Ol { Mg_2SiO_4	17.22		100.0
TiO_2	1.27	.016	1.0	Ol { Fe_2SiO_4	5.71		
Cr_2O_3	0.24	.002		Il	2.43		
S	0.06	.002		Mt Fe_3O_4	4.87		
H_2O+	3.46			$FeCrO_4$	0.36		
H_2O-	0.47			Fe_6S_7	0.11		
				Σ fem	72.28		
					95.51		
	99.82		100.0				

Rossweinose.

Osann's system:	s	A	c	F	n	a	c	f	k
	43.6	0.3	4.5	46.7	6	0	2	18	0.77

metric analysis gave 29.1 % of soluble components, i. e. olivine and the products of its alteration. From the insoluble part the ores and the pyroxene were separated with methylene iodide, and the residue, consisting of amphibole, was analyzed with the following result (I). For comparison the analysis of edenite from Saualpe [1] may be given (II).

The figures are not so reliable as would be desirable, because only one gram of the substance was obtained and its purity was not perfect. They give, however, an idea of the chemical nature of this amphibole. The optical properties are in accordance with the analytical conclusion that it is an edenite. 2 V is very nearly 90°, as the mineral gives in sections ⊥ one axis a straight axial bar, so that the

[1] C. F. Rammelsberg, *Pogg. Ann.*, **103**, p. 441, 1858, quoted by Dana, »The system of Mineralogy», p. 393, 1899.

Table XII.

	I	Mol. prop.		II
SiO_2	49.32	.816	816	49.33
Al_2O_3	9.38	.092	104	12.72
Fe_2O_3	1.89	.012		1.72
FeO	5.77	.081		4.63
MnO	0.16	.003	487	—
MgO	16.12	.403		17.44
CaO	13.22	.236	236	9.91
Na_2O	(0.34)[1]	—		2.25
K_2O	(0.16)[1]	—		0.63
TiO_2	1.20	.015		—
H_2O	n. d.			0.29
	(97.56)			99.13

optical character can not be determined. The mean index of refraction is:

$$\beta_{Na} = 1{,}635.$$

The birefringence is between 0.020 and 0.023. The arrangement of the axes of optical elasticity is: $a = \mathfrak{a}$, $b = \mathfrak{b}$, $c : \mathfrak{c} = 14°$. In reflected light the colour is brownish grey. The absorption colours are: $\mathfrak{a}$ = pale brown $<$ $\mathfrak{b}$ = brown = $\mathfrak{c}$ = greyish brown. In sections about 0.1 mm thick the pleochroism is strong, and in ordinary rock slices still noticeable.

The monoclinic pyroxene is colourless in all translucent sections. Cleavage traces along the faces 110 and 100 of the type characteristic of diallage are visible in basal sections. Determined by the immersion method the main refractive index is:

$$\beta_{Na} = 1{,}683.$$

$c : \mathfrak{c} = 45°$ approximately; the optical character is positive. $\gamma - \alpha$ is between 0.023 and 0.025. The axial angle, determined with Klein's lens, gave the result:

$$2\,E = 89°\ 56',$$

[1] Calculated from the rock analysis, assuming all the alkalis to be present in the amphibole.

from which the value 2 V = 50° was calculated graphically. All these properties agree with data formerly given for diallages, but for no other monoclinic pyroxenes. Thus the axial angle is smaller than in augites and even smaller than in the diopside-hedenbergite series, while c : c is greater than it is in the diopside. As comparative studies on the diallages have not yet been made, no conclusions can be drawn as to their chemical composition. In the process of calculation, the percentage of pyroxene was added to that of amphibole, this being justifiable owing to the small amount of the former present.

After subtracting the oxides contained in the amphibole and the pyroxene, the remainder represents the amount of serpentine, olivine, spinel, chromite and pyrrhotite. The chromite and pyrrhotite were calculated on the assumption that they contain the theoretical molecules $FeCr_2O_4$ and Fe_6S_7. The spinel in thin sections is transparent and of a green colour. In order to determine the composition of this mineral, 14.2 mg were separated by treating a quantity of the rock-powder with hydrofluoric and sulphuric acids, whereby all the chromite was dissolved. From this amount 7.6 mg $Fe_2O_3+Al_2O_3$, 2.0 mg MgO and only a trace of Cr_2O_3 were obtained. Consequently we have a pleonaste with about 75 % $MgAl_2O_4$ and 25 % $FeAl_2O_4$ or 69 % Al_2O_3, 10 % FeO and 21 % MgO.

The olivine is optically positive with 2 V = nearly 90°. The mean index of refraction was determined by the immersion method in a thin section ⊥ an optical axis. The result obtained was:

$$\beta_{Na} = 1{,}674.$$

According to the results of H. Backlund,[1] such an olivine should contain about 13 percent of the fayalite molecule or 46.9 % MgO, 12.6 % FeO and 40.5 % SiO_2.

After the subtraction of all the above-mentioned compounds we are left wit the following remainder:

SiO_2	Al_2O_3	Fe_2O_3	$FeO+MnO+NiO$	MgO	CaO	TiO_2	Cr_2O_3	H_2O	Sum
1.82	1.33	1.97	4.38	0.77	0.26	0.42	0.10	3.46	14.51

All errors due to the difference between the assumed, theoretical composition and the actual composition of the minerals already calculated will have accumulated here, and so the figures cannot

[1] *Travaux du Musée Géologique Pierre le Grand, Ac. Imp. St. Pet.* **3**, p. 77, 1909.

give the true composition of the minor constituents comprised by this remainder. These minor constituents include serpentine as well as a chloritic substance and much iron ore in a dusty condition, which is distributed in the unaltered olivine as well as in the serpentine.

The serpentine varies from greenish brown to golden yellow in colour which is always much more intense than that of the other silicate compounds. Structurally the mineral is a laminated serpentine with a very low birefringence. The formation of the serpentine has proceeded along the fractures of the olivine.

The structure of the peridotite is metamorphic with porphyritic individuals of olivine and pyroxene. The ground-mass is composed of amphibole individuals measuring about 0.1 mm in diameter. They have an elongated prismatic form, often euhedral on (110). The idiomorphism is also distinct towards other individuals of the same mineral arranged in different positions. Excepting this peculiarity the amphibole-mass offers the same appearance as some granoblastic quartz-feldspar rocks.

The diallage individuals scattered throughout this ground-mass are conspicuosly larger than the grains of hornblende, often measuring 0.5 to 1 mm in diameter. The amphibole is frequently intergrown with the pyroxene, being idioblastic towards it. It cannot be said with certainty whether these individuals of pyroxene are relics of porphyritic phenocrysts or xenoblastic recrystallized individuals.

With regard to olivine, the occurrence of this mineral as original phenocrysts is beyond any doubt. In the analyzed specimen the individuals often attain a size of 0.5 mm in diameter, and in the largest part of the area they are still greater, often 20 mm. They appear as rust-coloured patches on the weathered surface of the rock, hollowed a little below the ground-mass. These phenocrysts have often rounded ellipsoidal forms and are commonly divided into many fields, separated from each other not only by the products of alteration, but also by the edenite which has afterwards corroded and replaced parts of olivine as well as of diallage.

Pleonaste and chromite occur in the form of irregularly shaped grains of smaller dimensions than any other constituents. It cannot be ascertained on structural grounds whether they are original or of metamorphic origin. It is more probable that they are original considering that these minerals are commonly found in igneous rocks of peridotitic composition.

Before the origin of the edenite can be discussed we must know whether the rock is of infracrustal or supercrustal origin. At first sight the occurrence of large phenocrysts in a fine-grained ground-mass would suggest a volcanic origin but the mode of occurrence is not in accordance with this hypothesis, as it is certainly not the mode of a tilted lava flow but that of a plutonic massif. The rocks show no bedding, but are rather homogeneous, passing laterally from a rock of gabbroid composition into different kinds of peridotites of which only the most widely distributed type was described above. The feldspar-bearing varieties, found in many parts of the area, closely resemble the other gabbros in this region. They have not yet been studied in detail. As to the peridotites: on closer examination of different parts of the area one would certainly detect gradations in different directions, as is the usual rule in gabbro-peridotitic massifs. We shall give details only of one more example.

Bronzite-bearing amphibole-peridotite north of Pyhälampi, Suomusjärvi.

Within this peridotite-area, North of the middle part of the long lake Pyhälampi, the rock is markedly porphyritic with dull grey, rounded and equant phenocrysts of bronzite, which measure from about 0.5 to 1.5 cm in diameter. The ground-mass consists of the same minerals as the analyzed sample, but having a much smaller amount of olivine and its alteration products.

The bronzite has been much altered to a fine-grained substance with low interference colours, probably belonging to the serpentine group but having none of the characteristic features of this mineral. Some parts of the bronzite, are unaltered. Cleavage parallel to (110) is rather distinct. The pinacoidal cleavage parallel to (100) as well as that parallel to (010) determines short but well marked cracks. Besides these apparently true cleavages, a parting parallel to (010) has given rise to long but not quite rectilinear cracks. On the whole the prismatic cleavage is by far the most distinct. There is nothing to be seen of any lamellar interpositions parallel to (100), which are common in bronzites from nonmetamorphic igneous rocks. It must, however, be noted here that the positions of the crystallographic axes a and b have been taken on the assumption that the optical arrangement is that common in unaltered bronzites, i. e. that a = $\mathfrak{b}$ and b = $\mathfrak{a}$. The prismatic cleavage is not distinct enough to permit the identification of the acute and obtuse angles with any certainty. The majority of the direct determinations led to the opposite result: a = $\mathfrak{a}$; b = $\mathfrak{b}$. The optical character is positive. Of the indices of refraction β_{Na} was determined directly by the immersion method. Then α was obtained by determining $\beta - \alpha = 0.0081$ with the Babinet compensator. Finally the axial angle about $\mathfrak{c}$ was determined approximately with the Fedorow universal stage in parallel polarized light, using glass hemispheres. The result obtained was $2\,V = 85°$. From this value and from α and β the approximate figure for γ was calculated, and we have the indices

$$\alpha_{Na} = 1.680; \ \beta_{Na} = 1.688; \ \gamma = 1.698.$$

Although the variability of the refringence with the relative amount of the ferro silicate is very pronounced in the isomorphic series of rhombic pyroxenes, these relations have not yet been wholly established. Instead the optic axial angle has been used since the classic work of Tschermak (1871). From the axial angle as compared with the available data, this bronzite should contain about 16 % FeO, a result agreeing also with what is known about the refractive indices.

Plechroism is distinct also in thin slides: $\mathfrak{a}$ = pale pink, $\mathfrak{b}$ = colourless and $\mathfrak{c}$ = colourless; the absorption so far as it could be determined is $\mathfrak{a} < \mathfrak{b} = \mathfrak{c}$. This result is different from those usually given in textbooks, according to which the absorption is greatest for rays vibrating parallel to $\mathfrak{c}$.

Evidently the bronzite in this rock is a substitute for olivine and, the other components being the same as in the analyzed rock, the only important difference in composition is probably that the amount of silica is here somewhat greater.

As the rocks have been plutonic, they must have been holocrystalline. Whereas the olivine and the bronzite were probably of primary origin, we are here confronted with the question: what was there in place of the amphibole, which seems to be of a metamorphic origin? It will be useful to find what minerals non-metamorphic plutonic rocks with a similar composition may contain. The following analyses are given for comparison (table XIII).

I. Peridotite (rossweinose), Pyhälampi, Suomusjärvi.

II. Hornblende-picrite (wehrlose), Ty Croes, Anglesey, Wales, analyzed by J. A. Phillips.[1]

III. Peridotite (rossweinose), Crystal Falls, Mich., analyzed by H. N. Stokes.[2]

N:o II is a deep-seated rock containing hornblende, olivine, monoclinic pyroxene and green spinel. N:o 3 is a coarse-grained deep-seated rock containing, as primary minerals, olivine, augite, bronzite, and a brown amphibole, showing $\mathfrak{a}$ = light cream yellow, $\mathfrak{c}$ = yellowish brown, $\mathfrak{b}$ = reddish brown. The minerals are named in the order of crystallization, which is identical with that in the analyzed rock from Pyhälampi.

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[1] T. G. Bonney, *Q. J. G. S.* XXXIX. p. 254, 1883.

[2] J. Morgan Clements, *J. G.* VI, p. 386, 1898.

Table XIII.

	I	II	III
SiO_2	42.96	42.87	44.99
Al_2O_3	8.11	10.63	5.91
Fe_2O_3	3.31	3.44	3.42
FeO	10.36	18.14	8.30
MnO	0.23	trace	trace
NiO	0.05	—	—
MgO	19.30	16.27	21.02
CaO	9.65	9.11	8.79
Na_2O	0.24	0.92	0.91
K_2O	0.11	0.13	0.72
TiO_2	1.27	trace	0.97
P_2O_5	—	trace	0.05
Cr_2O_3	0.24		0.25
CO_2	—	2.70	
S	0.06		
H_2O	3.93	3.00	3.82
	99.82	99.95	99.17

Thus in these and many other amphibole-peridotites[1] the mineralogical composition is the same as in the rock of Pyhälampi. Consequently it appears that the minerals are possibly of the same species as those in the original rock, though the amphibole has been completely recrystallized.

[1] Vide: H. Rosenbusch, »Mikroskopische Physiographie.» II, 1, p. 457, 1907.

Amphibolites.

Amongst the amphibolites we include all more or less perfectly crystalloblastic rocks consisting mainly of amphibole and plagioclase. This class therefore includes very many kinds of rocks which differ both in composition and structure. A feature common to most of them is a sill-like habit of the rock-masses intercalated with or intruded into the leptites and following, on the whole, the general strike of these.

Amphibolites of volcanic origin.

Description of the occurrences.

Several beds of amphibolite occur within the watershed of Lake Orijärvi. This area is a part of the contact-aureole of the Orijärvi granite mass, but the amphibolites are very well preserved and retain many traces of their primary structure. In general, these rocks have offered a remarkable resistance to p n e u m a t o l y t i c action.

In the field, evidence of the volcanic origin of the amphibolites is apparent on the islands of Hepolahdensaari and Kirppuholma. The middle part of the former island consists of a fine-grained dark rock which has some faintly pronounced schistosity. Generally it is even-grained and its texture is perfectly crystalloblastic (pavement structure), but in some parts the weathered surfaces show whitened grains of plagioclase, each some two or three mm in diameter and having rounded and fringed forms. Under the microscope such crystals appear as blastoporphyritic individuals. On the northern and southern shores of the island the amphibolite forms thin laminae which are intercalated with layers of limestone and leptite (cf. fig. 2 page 13). In the neighbourhood of these intercalations, the amphibolite is always very fine-grained and contains ragged inclusions of calcite. On the surface the calcite has been eaten out by solution. The pits thus formed are in part arranged in rows parallel to the strike. At first sight one gets the impression that these calcitic inclusions represent amygdules and that the belts where the amygdules occur less abundantly are the more massive portions of ancient basaltic lava-flows (fig. 17).

On the northern shore of the little island Kirppuholma such calcitic amygdules are numerous, and the appearance of the surface of the rock is very like the slaggy surface of a recent lava-flow.

Similar »slaggy» amphibolites have been observed on the island of Kylänsaari, near the Paavo farm, at several points at the eastern shore of Lake Orijärvi and on the shores of Lake Määrijärvi.

Fig. 17. Amphibolite containing amygdules of calcite. Hepolahdensaari, Orijärvi.

East of Orijärvi near Lake Haukialampi, primary features are not so well preserved either in amphibolites or in the leptites. Recrystallization has proceeded farther, and a rather coarsely crystalline and distinctly schistose amphibolite has resulted. This may be due to the fact that the eastern part of the Orijärvi granite occurs more after the manner of a true deep-seated rock than does the western part (cf. p. 14).

On the southern shore of Lake Orijärvi amphibolites are seen in contact with the granite. Near the cottage of Niemi the surface of contact is well exposed. The granite is the newer rock and has caught up sharp-edged fragments of the amphibolite, which, however, at the immediate contact, shows the same porphyritic habit as has been noticed on the island of Hepolahdensaari. To the West of the lake similar well preserved amphibolites occur quite near the granite-contact.

At the eastern shore of the northern part of Lake Määrijärvi, west of the granite mass, the amphibolites, as also the leptitic rocks, seem to be more affected by the contact action of the granite than elsewhere. In the amphibolite the hornblende has become bleached and has assumed acicular shapes characteristic of actinolite. Tigerstedt therefore called the rock in question an actinolite-schist (strålstenskiffer). The bleached amphibole is in fact cummingtonite. This variety will be described in connection with other contact-altered rocks of the Orijärvi aureole.

The zone of metamorphosed supercrustal eruptives continues to the West of Lake Määrijärvi. Here also the rocks show frequent transition from phaneroporphyritic to even- and fine-grained varieties. The ground-mass of most of these rocks is fairly uniform, but there is considerable variation in the size of the phenocrysts. These have generally almost rectangular sections and are always very prominent upon the weathered rock-surface, where having been whitened they show up well against the dark ground-mass. As a rule, no foliation is observable in this part of the area.

The inner part of the peninsula named Riilahden Sorro consists entirely of a porphyritic amphibolite which grades outwards into a fine-grained non-porphyritic amphibolite. This is bordered by leptite or limestone. The porphyritic rock contains an abundance of phenocrysts both of plagioclase and of amphibole (uralite, pl. II, fig. 1).

In many places the porphyritic amphibolites show amygdaloidal structure. The outer shell of the amygdules often consists of plagioclase, and when the rock is broken, the amygdules remain unbroken and appear as globular or pea-like nodules on the fractured surface. The kernels may consist either of calcite or of silicate minerals. A notable outcrop of this rock occurs on the northern part of a low cape, named Valvinokka, at the western shore of Lake Määrijärvi. The amygdaloidal rock which is bordered by limestone, passes laterally into a usual porphyritic amphibolite, and is cut by numerous curving dikes of a fine-grained dark green amphibolite.

Between the northern end of Lake Määrijärvi and Lake Kiskon Kirkkojärvi there occurs a lens-shaped mass of porphyritic amphibolite in which the phenocrysts sometimes reach 10 mm in diameter. As tuffitic rocks occur at the northern border of this mass, it seems clear that the amphibolite was formed as a true extrusive rock. To the south of the main mass dikes of a similar rock occur at several places (cf. map II).

The porphyritic amphibolites described above form a continuous belt which is only interrupted by the central granite mass of Orijärvi. Probably they belong to one particular geological horizon. Another belt of supercrustal amphibolites is found to the North of Lake Orijärvi. The horizon of this northern belt is separated from the former by an intrusive sill of amphibolite which ends off towards the West near the Orijärvi mines. The best exposure of these supercrustal amphibolites is found to the South of the cottage of Lahtiranta. The rock forms a mass whose southern part consists of an even-grained amphibolite which passes gradually through a porphyritic variety into an amygdaloid associated with tuffitic agglomerates.

The horizon cannot be followed continuously towards the West, but on the same line of strike, some three km farther, a porphyritic amphibolite crops out on the hill of Hyyppiämäki in typical aspect and here also is associated with agglomerates. The agglomeratic rocks will be described later.

The amphibolite near Workmen's Association, Orijärvi.

Two analyses of the blastoporphyritic amphibolites were made by the writer. For one of them a specimen was collected from the rock near the house of the Workmen's Association at the Orijärvi mine, only a few meters from the contact with granite. The analysis gave the following results.

Table XIV.

	%	Mol. prop.	Mol. %	Norm.		Mode.	
SiO_2	52.98	.883	56.2	O	0.96 %	Quartz	3.5 %
Al_2O_3	17.49	.172	10.9	Or	1.67	Plagioclase	
Fe_2O_3	0.54	.003		Ab	27.25	$Ab_{45}An_{55}$	56.3
FeO	6.39	.089	6.3	An	32.53	Hornblende	39.0
MnO	0.13	.001		Σ sal	62.41	Titanite	1.2
MgO	6.00	.150	9.5	Di $CaSiO_3$	9.78		100.0
CaO	11.33	.203	12.9	Di $MgSiO_3$	5.80		
Na_2O	3.16	.052	3.3	Di $FeSiO_3$	3.70		
K_2O	0.31	.003	0.2	Hy $MgSiO_3$	9.20		
TiO_2	0.78	.010	0.7	Hy $FeSiO_3$	6.47		
H_2O+	0.42	—	—	Il	1.52		
H_2O-	0.15	—	—	Mt	0.70		
				Σ fem	37.17		
	99.68		100.0		99.58		

Hessose.

Osann's system:	s	A	C	F	n	a	c	f	k
	56.9	3.5	7.4	21.3	9.4	2	4.5	13.5	1.00

Sp. g. 2,91.

Under the microscope this rock shows a rather homogeneous structure so that the actual mineral composition could be determined geometrically with a fair degree of accuracy. Two series of determinations were made:

	I	II	Average	Sp. g.
Quartz	3.8 vol %	63.7 vol %	3.8 vol %	2.64
Plagioclase	60.0 »		60.0 »	2.69 (calculated)
Hornblende	35.1 »	35.4 »	35.2 »	3.17 (determined)
Titanite	1.1 »	0.9 »	1.0 »	3.5
	100.0 %	100.0 %	100.0 %	

Supposing that all the alkalis are present in the plagioclase, the actual amounts of albite and potash feldspar are the same as in the norm and the percentage of anorthite must be $56.3-(1.67+27.25) = 27.4$. The plagioclase would then have the molecular composition $Ab_{51}An_{49}$. But it may be taken for granted that some of the soda and potash enter into the composition of the hornblende and consequently that the plagioclase is more calcic. The microscopic examination showed that such is the case.

P l a g i o c l a s e occurs in two generations: one representing the phenocrysts of the original crystallization, and another, formed during metamorphism. The grains of the latter have an average size of 0.05 mm in diameter and show well developed polyhedral forms towards each other as well as towards the quartz which also appears in the ground-mass. The plagioclase grains rarely show an indistinct zonal structure, the most sodic mixture forming the kernel, but the difference in the position of extinction is very slight. Twinning occurs occasionally according to the albite law, but usually only one or two thin lamellae are seen crossing each individual crystal. The plagioclase shows refractive indices considerably higher than those of quartz. The maximum extinction angle in section $\perp$ (010) was in numerous cases found to be about 28°, which might represent the average of the ground-mass feldspar, which thus might be a labradorite Ab_1An_1. This feldspar is always quite unaltered.

The biggest of the porphyritic individuals are about 1.0 × 0.8 mm. Their borders are ragged as though the grains of hornblende, plagioclase and quartz had corroded them by their enlargement. Small rounded crystals of quartz and euhedral prisms of hornblende occur as inclusions in them, sometimes in such quantities that the inclusions seem to build up a hornfels mass, in which the big plagioclase appears as a skeletal individual. No distinct zoning can be seen in these grains, but in their central parts they are sometimes turbid, the turbidity being apparently due to the development of zoisite. They are always twinned according to the albite law and often according to Karlsbad and pericline laws also. Chemically these crystals seem to be a little more calcic than the plagioclase of the ground-mass. The maximum extinction angle in the symmetrical zone observed in the phenocrysts was 34° 30′ which indicates the mixture $Ab_{40}An_{60}$. A section cut ⊥ (001) and (010) gave an extinction angle of 30°, corresponding to a composition $Ab_{44}An_{56}$.

The plagioclases vary from labradorite Ab_1An_1 to labradorite-bytownite Ab_2An_3 and their mean composition may be not far from $Ab_{45}An_{55}$. This value has been taken as the basis for the calculation of the composition of h o r n b l e n d e which works out as follows. As no microcline was present the amount of K_2O is divided proportionally between plagioclase and hornblende.

Table XV.

	%	Mol. prop.	
SiO_2	48.2	0.803	813
TiO_2	0.8	.010	
Al_2O_3	3.1	.030	38
Fe_2O_3	1.3	.008	
FeO	16.7	.232	871
MnO	0.3	.004	
MgO	15.7	.394	
CaO	12.3	.220	
Na_2O	1.0	.016	
K_2O	0.5	.005	
	99.9		

As the exact mean composition of plagioclase could not be ascertained and analytical errors accumulate in the calculation, the figures above can only be approximate. The MgO:FeO ratio is probably correct. Moreover, it appears with certainty that the percentage of sesquioxides must be considerably lower than in most rock-forming hornblendes which have hitherto been analyzed, and the composition must approach that of actinolite.

After titanite the hornblende is the most idioblastic component of this rock. It shows crystal faces of its own, not only in the prism-zone, but also terminal faces. The colours are rather pale and the pleochroism not very marked: $\mathfrak{a}$ = pale yellowish green, $\mathfrak{b}$ = brownish green, $\mathfrak{c}$ = grass green. Absorption $\mathfrak{b} > \mathfrak{c} > \mathfrak{a}$. $c : \mathfrak{c} = 16°$. Mean index of refraction, measured by the immersion method:

$$\beta_{Na} = 1.655.$$

This value is in accordance with the FeO:MgO ratio (=0.60:1) shown by the analysis. Nevertheless the colours are pale, a fact indicating that this property in the hornblendes does not depend upon the amount of iron present, but rather on the amount of the aluminous molecules, which were found to be present only in small amounts.

Titanite has apparently been formed from ilmenite. It occurs in small aggregates and also as isolated rounded grains, and the former sometimes contain residues of lamelliform ilmenite. Among all the constituents of this rock titanite shows the greatest power of crystallization.

Apatite is found so rarely, that it did not occur in the geometric analysis. It appears as quite irregular grains without crystalline form.

Quartz occurs in the hornfels mass and as inclusions in the large plagioclases and also forms narrow veins, appearing as rows of polygonal grains. It seems that these veins have been formed during or before the last metamorphism, for hornblende has grown in these quartz individuals in the same manner as in the other minerals. No undulatory extinction has been observed in the quartz of this rock.

The occurrence of quartz in the manner described is important because it proves directly that silica has been added to the rock, and the chemical composition must have been correspondingly altered. The change has, however, probably been limited to an increase of the proportion of silica. On the whole, the analysis shows a composition very common to basalts and gabbros.

The amphibolite from Liipola, Kisko.

Another analysis was made of the porphyritic amphibolite from a broad dike in the village of Liipola. The results are given in table XVI.

The amounts of quartz, biotite and iron ores were estimated by the geometrical method, whilst the percentages of the other constituents were calculated from the chemical analysis. The potash feldspar was not observed actually.

Table XVI.

	%	Mol. prop.	Mol. %	Norm.		Mode.	
SiO_2	52.39	0.873	56.4	Q	4.56 %	Quartz	4.0 %
Al_2O_3	17.56	.173	11.2	Or	3.34	Potash feldspar	2.0
Fe_2O_3	1.33	.008		Ab	18.34	Plagioclase	
FeO	11.27	.157	11.3	An	36.70	($Ab_{50}An_{50}$)	34.5
MgO	4.87	.122	7.9	Σ sal	62.94	Amphibole	54.0
CaO	8.84	.157	10.2	Di $CaSiO_3$	2.90	Biotite	3.0
Na_2O	2.18	.035	2.3	Di $MgSiO_3$	1.20	Iron ores	2.5
K_2O	0.60	.006	0.4	Di $FeSiO_3$	1.72		100.0
TiO_2	0.72	.009	0.3	Hy $MgSiO_3$	11.00		
H_2O+	0.65	—	—	Hy $FeSiO_3$	16.76		
H_2O-	0.22	—	—	Mt	1.86		
				Il	1.37		
				Σ fem	36.81		
	100.63		100.0		99.75		

H e s s o s e, near A u v e r g n o s e.

Osann's system:	s	A	C	F	n	a	c	f	k
	56.7	2.7	8.5	20.9	8.5	1.5	5.5	13	0.95

The p l a g i o c l a s e of this rock occurs as large phenocrysts attaining a size of 5 mm in diameter, and as small grains of various sizes averaging about 0.1 mm, forming a part of the ground-mass. Both kinds seem to be nearly identical in composition and not far from $Ab_{50}An_{50}$. This value was arrived at by means of maximum extinction angles in the symmetrical sections. In its structural characters the plagioclase resembles that of the amphibolite described above.

The amphibole is a common green h o r n b l e n d e and not very dark in colour. The calculation gave as a result that the hornblende should contain 12.8 % Al_2O_3, 17.8 % FeO, 8.2 % MgO and 9.5 % CaO. We have here a further proof that the depth of colour in amphiboles bears no relation to the amount of FeO.

Remarks on the composition of the amphibolites.

The analyses quoted above probably represent an approximation to the composition of the greater parts of the amphibolites of volcanic origin in the area. In other specimens examined microscopically the plagioclases were mostly found to vary within similar limits to those discussed above.

Only in the region near the western shore of Lake Määrijärvi more sodic plagioclases were observed. Thus the plagioclase of the rock from Riilahden Sorro gave, in sections ⊥ (010), a maximum extinction angle of 20°, indicating the composition $Ab_{62}An_{38}$. The phenocrysts of the amygdaloid from Valvinokka gave, in sections ⊥ (010) and (001), extinction angles of about 18°, corresponding to $Ab_{64}An_{36}$. In the rock from Kiimasuo values from 20° to 22° were found, giving about $Ab_{60}An_{40}$. In all these cases the hornfelsic plagioclase is nearly identical in composition with the phenocrysts. At first sight therefore this rock might be classed with the andesites, a grouping which, however, its bulk composition does not support. These amphibolites show a deep-green hornblende in large excess of the plagioclase. If this hornblende, as its colour might indicate, were assumed to contain rather high a proportion of alumina, the total composition could be calculated as being nearly the same as that of either of the analyzed amphibolites, with somewhat more magnesia and iron oxides and less silica, but not less lime. Later on more evidence will be given to prove that in igneous rocks originally containing more (Mg,Fe) O in proportion to the femic lime than can exist in the hornblende, this mineral is formed during metamorphism at the expense of anorthite, i. e. the deficiency of femic lime is balanced by the lime contained in the plagioclase which will then become more albitic than it was in the original rock.

Sustschinsky (41 pp. 194—196) describes a fine-grained amphibolite from Multsilta (erroneously written »Multsila»), from the same region as the last-mentioned rocks. It is described as a »malchite-like rock», because of its resemblance to the malchite from Melibocus, Odenwald. According to Sustschinsky this rock consists of hornblende and sodic plagioclase; biotite is rarely found. The structure, illustrated by an excellent photomicrograph, closely resembles the granoblastic amphibolites from this same region which were examined by the present writer. An analysis of this »malchitelike» rock is given (p. 195), showing 55.06 % SiO_2, 18.27 % Al_2O_3, 2.19 % Fe_2O_3, 7.14 % FeO, trace of MnO, 6.76 % CaO, 3.42 % MgO, 4.83 % K_2O, 0.70 % Na_2O, 0.19 % P_2O_5; loss on ignition 1.21 %, sum 99.78. On the basis of these results Sustschinsky states that the composition of the rock differs from all known igneous rocks. This analysis, however, can hardly be correct. The amount of alumina in proportion to lime and alkalis seems too high for a rock consisting chiefly of hornblende and plagioclase. Moveover, no potash felspar having been found and biotite »occurring rarely», the figures representing the percentage of alkalis can hardly agree with the author's microscopic examination.

In general summary of the foregoing we may state that the composition of the amphibolites of volcanic origin described above varies within the limits of the basalts, with variable ratios between the femic and salic compounds. If secondary changes have taken place, they have not been of sufficient importance to obliterate the original bulk composition of the rocks.

On the other hand, by reason of the different effects of metamorphism, these rocks show great variability in the characters of the constituent minerals and their structure.

In the phenocrysts of plagioclase more or less well preserved primary features are found. Sometimes a primary zonal structure remains (pl. II, fig. 2). Thus in a slice taken from the large mass north of Liipola, the maximum extinction angle, in sections ⊥ (010), was 32° in the kernel and 25° at the borders, the limits between the different zones being of that rather sharply defined kind characteristic of primary zonality. A phenocryst of a little more than 10 mm in diameter, cut ‖ (010), showed three zones, in which the extinction angles, measured from the trace of the pericline twinning lamellae, were in the kernel 17°, in the outer shells 14° and 7° respectively, corresponding to a variation from a labradorite-bytownite to labradorite. More often, however, the phenocrysts show no zonal structure. That such structure did originally exist, in many cases at least, is shown by the fact that the inner parts of the crystals are somewhat turbid as a consequence of zoisitisation. The amount of zoisite and epidote as products of alteration of feldspars is, however, very small. No true saussuritized plagioclases have been found. When, as often is the case, the phenocrysts are quite clear and yet without any zonal structure, it is probable that they have recrystallized completely but have preserved their outlines.

On the whole, the primary forms have been well preserved, showing in sections ⊥ (010) a rectangular form. In this area the phenocrysts are not sheet-shaped, but almost always equidimensional, in contrast to the most Archaean labradorite-porphyrites of Finland. [1] When the ground-mass is fine-grained, the structure bears a close resemblance to that of non-metamorphosed porphyrites. The crystals, however, always show ragged outlines, due to the newly crystallized hornfelsic hornblende, plagioclase etc. The same minerals mostly occur more or less abundantly as poikiloblastic inclusions within the felspar phenocrysts (pl. II, fig. 1). Often these phenocrysts are divided

[1] J. J. Sederholm, »Studien über archäische Eruptivgesteine aus dem südwestlichen Finland», *T. M. P. M.* **12**, 1892, p. 170, 1892.

into somewhat differently oriented fields, as is also the case in many unaltered porphyritic rocks. At a further stage of metamorphism the phenocrysts begin to break up into a fine-grained hornfels mass. This granulation begins at the crystal borders, and in many cases whole crystals have been granulated (cf. pl. III, fig. 2, which shows the same phenomenon in a leptite). It is to be noted that this phenomenon is certainly not due to any process of mechanical deformation. It may occur in rocks which are devoid of visible foliation, while, on the other hand, in the tectonically disturbed and schistose parts the phenocrysts have often escaped the granulation process altogether.

The plagioclase of the ground-mass always shows a perfectly crystalloblastic structure, mostly of the pavement type. No such fine tabular plagioclase resembling the ground-mass feldspars of recent volcanic rocks were observed here. In composition the ground-mass plagioclase is often identical with the plagioclase of the phenocrysts, but it is just as often somewhat more albitic (cf. p. 102). When the phenocrysts are zonally built, the composition of the outermost zone is the same as that of the plagioclase of the ground-mass. Inverse zonal structure is frequently met with.

Phenocrysts of u r a l i t e occur rarely. They consist of fine fibres in subparallel positions. The colours are paler than those of the ground-mass hornblende. The primary idiomorphism may be seen in pl. II, fig. 1.

The c o m m o n h o r n b l e n d e, occurring as idioblastic prisms in the ground-mass, is certainly all of a metamorphic origin. This mineral shows great variability as to the intensity of the colour, probably depending upon the percentage of alumina (p. 103). Small amounts of a colourless amphibole are sometimes associated with the hornblende.

Of the accessories, only t i t a n i t e and i l m e n i t e occur in considerable amounts. The mutual relations of these two minerals offer some points of interest. Sometimes the titanite is idiomorphic and may be of primary origin, but more often it is leucoxene. The rocks often are devoid of any ore-minerals. In most cases ilmenite only is present and no titanite. As amphibolites with titanite and amphibolites which do not contain it may otherwise show quite the same characteristics, the difference can hardly be explained as an index of the stage of the metamorphism. It seems more plausible to assume the results of a chemical mass-action. Where lime is in excess, titanite is formed, where lime is deficient, ilmenite is the constant form. We will return to this subject later on.

The behavior of the amygdules during metamorphism deserves special attention. The following description is based on a study of the rock from Valvinokka, on the western shore of Lake Määrijärvi, where the phenomena are very typical. The amygdules are globular nodules of a size varying between one and ten mm. They are built up of a series of concentric zones consisting of different minerals (pl. II, fig. 3). The outmost zone may consist of plagioclase, but this zone, is sometimes wanting. Within this zone or making direct contact with the containing rock, a zone of diopside is always present. The inner part is mostly filled with calcite in a coarsely crystalline form. Sometimes there is much plagioclase in the inner zone, mingled with calcite, and this plagioclase has the same composition as that of the rest of the rock. In the instance under discussion it is andesine. In addition to these minerals the amygdules always contain some green hornblende which is present most abundantly in the outer parts of the diopside zone, but is never absent wherever diopside is seen. Diopside and hornblende are often associated in such a manner as to give the impression that the amphibole is being formed at the expense of the pyroxene. There are also amygdules without any kernel of calcite. Where metamorphism has proceeded further to the complete uralitization of the pyroxene, there is only the exterior plagioclase-shell to bear record of the former existence of an amygdule.

The pyroxene crystals are always large and in some cases the diopside-shell is formed as a single individual. Hornblende and andesine are usually seen as poikiloblastic intergrowth with the pyroxene.

The phenomena described above are interesting as showing that siliceous minerals and calcite may react together in a solid state to form silicates without the direct action of any adjacent hot intrusion. As will be described later, analogous phenomena may be observed wherever limestones and siliceous rocks in contact have been metamorphosed together.

Intrusive amphibolites.

Amphibolite north of Lake Orijärvi.

One of the most interesting amphibolites of the area is that which occurs as a long sill on the northern side of Lake Orijärvi. It is a fine- and even-grained rock with perfectly crystalloblastic structure, never showing any traces, megascopical or microscopical, of its primary habit. At its southern bounding wall it is in contact with the ore-bearing belt which is strongly affected by pneumatolytic metamorphism. At the southern margin of the sill pneumatolysis also seems to have taken effect upon the amphibolite giving rise to a change in its composition (p. 225).

Where these particular phenomena are absent, the rock shows no endogeneous or exogeneous contact-zones, all such features having been obliterated by various later metamorphic processes. The absence of the porphyritic, the amygdaloidal and the tuffitic varieties, so common in many other amphibolitic rock masses, speaks in favour of an intrusive mode of origin. This hypothesis is also supported by the outlines of the boundaries of this mass, which, in many places, cut across the strike of the adjacent rocks. The mass also sends out short apophyses, both at the southern and at the northern contact, e. g. near the cottage of Auranen, at the northern side of the mass (cf. map II). From these facts it seems justifiable to conclude that this amphibolite has originated as a large sill.

Considerable parts of the rock consist merely of plagioclase and amphibole, but generally a brown biotite is also present. The rock is always distinctly schistose by reason of the parallel arrangement of the

Table XVII.

	%	Mol. prop.	Mol. %	Norm		Mode	
						Plagioclase	
SiO_2	50.99	.850	53.1	Or	2.22 %	Ab_{53} An_{47}	36.45
Al_2O_3	15.18	.150	9.3	Ab	23.06	Amphibole	64.45
Fe_2O_3	1.87	.012		An	28.36	Ilmenite	0.46
FeO	8.09	.115	8.8	Σ sal	53.64	Pyrite	0.18
MnO	0.18	.002		Di $CaSiO_3$	6.03		101.54
NiO	trace	—		Di $MgSiO_3$	3.70		
MgO	10.00	.250	15.6	Di $FeSiO_3$	1.98		
CaO	8.60	.154	9.4	Hy $MgSiO_3$	15.60		
Na_2O	2.67	.044	2.7	Hy $FeSiO_3$	7.92		
K_2O	0.38	.004	0.3	Ol Mg_2SiO_4	3.92		
TiO_2	0.65	.009	0.6	Ol Fe_2SiO_4	1.84		
S	0.08	.003	—	Il	1.37		
Cr_2O_3	0.08	—	—	Mt	2.78		
H_2O+	0.95	—	—	Pyrite	0.18		
H_2O-	0.10	—	—	Σ fem	45.32		
	99.82		100.0		98.96		

Auvergnose.

Osann's system:	s	A	C	F	n	a	c	f	k
	53.7	3.0	6.3	27.7	9.0	1.5	3.5	15.0	0.92

prisms of hornblende and scales of biotite. There is no trace of cataclastic structure. The schistosity is strictly parallel to that in the adjacent schists, and with them it bends round the huge fold at the eastern end of Lake Orijärvi. This circumstance proves that the amphibolite is older than the latest folding of the schistose series. There is no direct evidence whether it is older or newer than the Orijärvi granite, because the rocks nowhere are in contact. Just the conformable occurrence as a sill makes it, however, most probable that the amphibolite is the older. Amphibolites newer than the granite always occur in this region more in the manner of cross-cutting dikes.

It would seem that the Orijärvi amphibolite was intruded at a time when the supercrustal series was still undisturbed by orogenic movement and that it consolidated comparatively near the surface, perhaps as a fine-grained dolerite.

A variety of this amphibolite devoid of biotite was chosen for quantitative examination from the rock near the Julin shaft at the Orijärvi mine. A chemical analysis made by the writer gave the results quoted in table XVII.

The mode given above was calculated from the analysis. An attempt was made to determine the mineral composition by the geometrical method, but it was found that the proportions between amphibole and plagioclase are so variable that two slices made from one specimen may give considerably different results. To calculate the mode it was necessary to know exactly the composition of one of the

Table XVIII.

	%	Mol. prop.		
SiO_2	49.58	.826	.834	
TiO_2	0.56	.008		
Al_2O_3	8.10	.079	.100	
Fe_2O_3	3.35	.021		
FeO	12.32	.171		
MnO	0.31	.004	.560	
MgO	15.41	.385		
CaO	7.99	.143	.143	.850
Na_2O	0.91	.015		
K_2O	0.11	.001	.057	
H_2O	0.56	.031		
	99.20			

two chief constituents. As the composition of the plagioclase is very variable, making it impossible to determine its average composition by optical means, the amphibole was separated by means of methylene iodide and analyzed (table XVIII). That portion was taken which floated in a solution whose specific gravity was 3,175 and sank in a solution with a specific gravity of 3,010. The mean density of the amphibole is therefore 3,093.

As there are no other magnesium-bearing minerals in the rock, all the MgO was assumed to enter into the composition of the amphibole and so the percentage of this mineral was obtained by means of the analyses. The residue was calculated as plagioclase and the two determinable iron ores. By starting from the residual amounts of CaO, Na_2O, K_2O, TiO_2 and S, there was a deficiency of 1.86 % SiO_2 and 0.27 % FeO, which causes the excess of 1.54 % in the summation of the mode. This non-agreement may be due to the accumulation of analytical errors in the two analyses, but it is probably also due in part to the non-homogeneity of the amphibole, which therefore may have been assorted in the process of separation so that the analysis does not represent the mean composition of the amphibole in the rock mass.

This analysis differs greatly from all those of common hornblendes from igneous rocks. While in the latter the ratio (Mg, Fe,Mn)O : CaO varies from 1.8 : 1 to 2.6 : 1,[1] it is here 3.92 : 1. The explanation is that in reality this rock contains two different amphiboles, the one of which probably differs little from those of certain igneous rocks, whereas the other, being practically devoid of lime, is a cummingtonite. This latter occurs abundantly in the contact-belt around the Orijärvi granite. At the southern border of the amphibolite sill the amphibolite passes gradually into a true c u m m i n g t o n i t e - a m p h i b o l i t e in which nearly all hornblende is replaced by the colourless ferro-magnesium amphibole, as will be described later in another connection.

In the rock now under discussion the main part of the amphibole is c o m m o n h o r n b l e n d e, as idioblastic prisms bounded by the faces (110) and (010), sometimes also by (110). Rarely the two pinacoids are predominant above (110). Twinning on (100) is present but is not very common. The mineral is optically negative with 2 V about 80° or somewhat less, $\mathfrak{a} = \mathfrak{a}$, $\mathfrak{b} = \mathfrak{b}$; $\mathfrak{c} : \mathfrak{c} = 16°$. $\mathfrak{a}$ = greenish yellow > $\mathfrak{b}$ = olive green = $\mathfrak{c}$ = green. $\gamma - \alpha = 0.023$ (approx.).

$$\beta_{Na} = 1,652.$$

[1] Vide: »Quantit. Classific.» table XIII.

C u m m i n g t o n i t e occurs with the common hornblende in such a way that it appears as though the latter had been partly bleached. Sometimes a crystal is completely surrounded by the bleached amphibole, but more often only the thin edges are so changed. Where the hornblende is built in larger frame-work crystals enclosing plagioclase, the bleaching extends far into the interior of the crystals. Small prisms often are colourless right through. The boundary-lines between the two amphibolies are sharp but not often straight or regular. The whole appearance gives one the impression that the bleaching is a secondary change and that the green hornblende had existed before the colourless variety was formed.

Unlike the hornblende the cummingtonite is optically positive with 2 V greater than that of the former. $a = \mathfrak{a}$, $b = \mathfrak{b}$, $c : \mathfrak{c} = 20°$. The birefringence is much higher than in the hornblende: $\gamma - \alpha = 0.026$ (approx.), but the refringence is a little lower:

$$\beta_{Na} = 1.642.$$

As calculated from the analyses, the mean composition of the p l a g i o c l a s e is $Ab_{53}\ An_{47}$. It has a beautiful pavement structure (pl. II, fig. 4), the polygonal grains measuring from 0.1 to 0.4 mm. Twinning lamellae, of the albite type, are very rare, and most of the grains are quite untwinned. Many of them show a marked inverse zonal structure, i. e. the kernels are more sodic than the shells (pl. II, fig. 4). Moreover, even when the crystals are homogeneous, their composition is very variable. This appears from the following determinations of the extinction angles. Only those sections normal to (010) and (001) in which the sharpness of the cleavage cracks proved the position to be strictly correct were used.

Zonal crystals

1.	Maximum extinction angle, sections ⊥ (010):	kernel 17°; $Ab_{67}An_{33}$	shell 36° $Ab_{37}An_{63}$
2.	» » » » » »	kernel 25°; $Ab_{55}An_{45}$	shell 31° $Ab_{44}An_{56}$
3.	Extinction angle in section ⊥ (010) and (001):	kernel + 24°; $Ab_{56}An_{44}$	shell + 27° $Ab_{50}An_{50}$
4.	» » » » » » »	kernel + 23°; $Ab_{58}An_{42}$	shell + 32° $Ab_{10}An_{60}$
5.	» » » » » » »	kernel + 23°; $Ab_{58}An_{42}$	shell + 27° $Ab_{51}An_{49}$
6.	Extinction angle in section ⊥ $\mathfrak{a}$:	kernel 23°; $Ab_{55}An_{45}$	shell 32° $Ab_{40}An_{60}$

Homogeneous crystals

1.	Maximum extinction angle in sections ⊥ (010):	34° $Ab_{40}An_{60}$
2.	Extinction angle in section ⊥ (010) and (001):	+ 30° $Ab_{46}An_{54}$

I l m e n i t e occurs in the form of irregularly shaped or tabular crystals, enclosed in the amphiboles as well as in the felsdpar. It is noteworthy that in this amphibolite leucoxene was never found, though a great number of thin slides were examined. As leucoxene is very common in amphibolites which do not contain cummingtonite, but was never found in the cummingtonite-bearing varieties, it is evident that its absence in this case is due to deficiency of lime.

No apatite has been detected. Minute rounded prisms of the shape characteristic of apatite, are seen, on closer examination, to be new-formed crystals of cummingtonite.

The analysis of this amphibolite shows unmistakeable affinities with numerous igneous auvergnoses (basalts as well as dolerites and gabbros), and it may be said that its composition is throughout possible for an igneous rock. The percentage of (Mg,Fe)O in proportion to CaO is, however, larger than in most igneous rocks of a gabbroid composition, the hypersthene-bearing types not excluded. But if some two percent of (Mg,Fe)O were replaced by CaO, the analysis would be nearly identical with a large number of analyses of igneous auvergnoses and also of many amphibolites of igneous origin.

The specimen of the Orijärvi amphibolite used for the analysis was taken some three meters from the southern boundary of the sill. Going from this point towards the boundary the rock passes gradually into a variety in which the main part of the amphibole consists of cummingtonite, while the plagioclase is present in equal amount and has the same composition as in the inner mass. This marginal variety might be regarded as an original product of differentiation, but it is more probable that its composition has been altered by the same pneumatolytic process which has been active in the adjacent ore-bearing rocks. It cannot therefore be said with any certainty, whether the composition as represented by the above analysis is quite original or not.

There is, however, an important fact in favour of the supposition that the large proportion of (Mg,Fe)O is an original feature of the Orijärvi amphibolite: The colourless amphibole, in small amount, is uniformly present in all parts of the rather extensive rock-mass. It is not probable that any metasomatic agency would have yielded such a homogeneous product.

Dikes of amphibolite.

Intrusive dikes of amphibolites occur very frequently in all parts of the Orijärvi area. Some of these are probably connected genetically with the volcanic amphibolites, while others show a more independent occurrence. Broadly speaking, the dikes as a whole follow the strike of the adjacent schists. Examined in detail their transgression obliquely across the strike is not infrequent, as illustrated by fig. 18.

Many of them are composed essentielly of hornblende and labradorite, and have the chemical composition of basalts or dolerites, but their composition varies considerably. Sometimes hornblende is predominant over plagioclase, the latter being nevertheless rather sodic, in other cases plagioclases of various composition are predominant.

The writer has not examined a sufficient number of examples to undertake any exhaustive treatment of the subject. The group of amphibolitic dike-rocks which intersect the oligoclase-granites

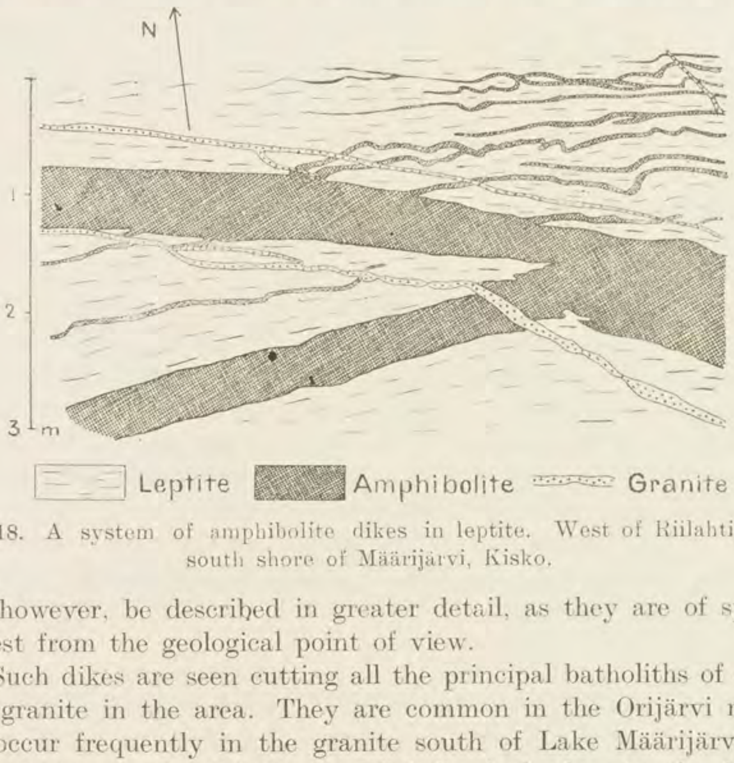


Fig. 18. A system of amphibolite dikes in leptite. West of Riilahti, the south shore of Määrijärvi, Kisko.

will, however, be described in greater detail, as they are of special interest from the geological point of view.

Such dikes are seen cutting all the principal batholiths of oligoclase-granite in the area. They are common in the Orijärvi massif and occur frequently in the granite south of Lake Määrijärvi. In the neighbourhood of Lake Iso-Kiskojärvi, farther to the South, I have not observed such dikes, but on the southern border of that same granite-diorite area they are again very numerous as well as in the southernmost massif, south of the railway-line.

They are always rather narrow dikes, measuring from a few centimeters to one or two meters in width and have no definite strike. They are true fissure-dikes, and make sharp straight-line contacts with the granite.

Some particular cases from the neighbourhood of Orijärvi may be taken as examples of the petrography of these dikes.

Near the farm of Hauksuo, west of Lake Määrijärvi, a narrow dike cuts a migmatite of granite and gabbro normally to its strike (fig. 15, page 82). The intersecting amphibolite is composed of plagioclase and pale green hornblende, with smaller amounts of biotite, titanite and apatite. The plagioclase, forming about 2/3 of the whole, occurs in small polygonal individuals, whose composition is about $Ab_{70}An_{30}$, and in larger crystals with a primary zonal structure, in which the kernels contain about 65 % and the shells 77 % Ab. The latter are apparently relict phenocrysts, a primary idiomorphism being clearly visible in the contours of the most calcic kernels, while the structure is otherwise perfectly granoblastic. A parallel structure is well marked, due not only to the arrangement of hornblende and biotite, but also to the parallellism of the elongated grains of plagioclase. The strike of the foliation is parallel to the walls of the dike and *perpendicular to the strike of the adjacent rock*. This is a metamorphosed dike-rock of a dioritic composition.

Immediately south of the mining field of Orijärvi a dark dike cuts the contact-line between the oligoclase-granite and the cordierite-gneiss nearly at right angles (see fig. 25, page 235). About 2/3 of the rock is of green hornblende in small idioblastic prisms. The rest consists chiefly of plagioclase, while biotite and titanite occur in small amounts. Plagioclase is found only as a granoblastic mass with pavement structure. Inverse zonality is common. In a section ⊥ (010) and (001) the extinction angles are: in the kernel 28°, corresponding to a mixture $Ab_{55}An_{45}$, in the shell 35°, agreeing with $Ab_{40}Ab_{60}$. The maximum extinction angle in sections ⊥ (100) in the homogeneous individuals is 32° ($Ab_{43}An_{57}$). Thus the composition of this rock must be very similar to that of the great amphibolite sill at the northern side of the mining field (page 109). There are two differences: Firstly, the hornblende of this dike-rock shows no trace of cummingtonite, and secondly, only titanite and no ilmenite is present here. Both differences may be explained by the fact that this dikerock is somewhat richer in lime.

Here also the rock is markedly schistose in the direction of the strike of the dike or at right angles to the very well developed foliation of the country-rocks. — This dike is a basaltic rock which has been completely recrystallized.

Between the mines of Orijärvi and Iilijärvi, west of the cottage of Grönqvist (fig. 52, page 235), a dark dike, in some places divided into two parallel dikes (fig. 19), cuts the andalusite-bearing and brecciated rock (p. 212) without showing any traces of brecciation or pneumatolytic influence, thus proving that it also is younger than the granite.

The rock contains about 70 % of green hornblende, the light component being labradorite, about Ab_1An_1. Titanite and a trifling amount of black iron ore occur as accessories. A parallel structure along the strike of the dike is well pronounced, but there is also a miniature folding normal to this direction and parallel to the schistosity of the country-rock (pl. II, fig. 5). The small prisms of hornblende are bent or broken, and new-formed epidote along the principal shearing-planes is abundant. This deformation is, however, chiefly of a mechanical nature.

A parallel metamorphic structure in amphibolite dikes, independent of the schistosity of the adjacent rocks, is of common occurrence

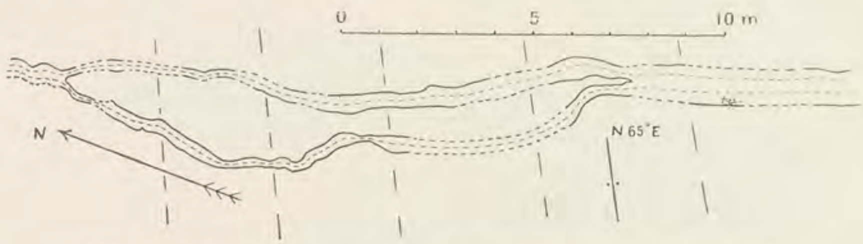


Fig. 19. Amphibolite dike in andalusite-bearing schistose rock, Near Grönqvist, Orijärvi.

in all parts of the Archaean rock-crust of southern Finland with which the writer is acquainted. Other Finnish geologists have made the same observation.

When following the general strike, the dike-rocks are, of course, foliated parallel to that strike, but when they transverse the strike, they show a schistosity of their own. Foliation transverse to the dike is often also present, but it is then noticeable that this foliation belongs to a later period, and that the rock is folded. The earlier parallel structure usually has not been wholly destroyed by the imposition of the later.

Dikes cutting non-foliated granites may also be schistose parallel to their length. In fact, this is a feature common to all Archaean amphibolitic dikes in Southern Finland. It must be observed that no metamorphic dike-rocks have been seen cutting the granites of the coast-type (in this paper termed microcline-granites). In those latest granites only non-metamorphic diabases, basalts and glassy rocks form dikes. It must therefore follow that the time of eruption of the amphibolitic dikes is between the periods when the two granites solidified.

The foliation parallel to the elongation of dikes seems to be a feature of the amphibole-bearing dike-rocks which are metamorphosed. In aplitic or pegmatitic or granitic dikes the writer has not observed this phenomenon.

When comparing the dikes in question with non-metamorphic dikes of similar composition and geological mode of occurrence, the conclusion seems evident that they originally possessed a doleritic or basaltic mineral composition and a non-foliated structure. To explain the origin of the foliation it is not necessary to assume orogenic movements and stress in more than one direction. The rock was of such composition that hornblende could be formed on metamorphism.

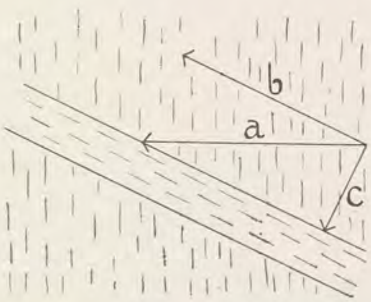


Fig. 20.

In accordance with the principle of Riecke the individuals of this mineral, when crystallizing under stress, assume a parallel arrangement. The possibility of the formation of such minerals gives the rock a property which may be termed m e t a m o r p h i c p l a s t i c i t y and under the conditions of stress allows the rock to suffer plastic deformation which in bulk is equivalent to plastic flow. Adjacent rocks either have no such plasticity or have it only in a smaller degree. When therefore the direction of the stress is oblique to the direction of dike (fig. 20), the component b of the stress a remains inactive, while the component c, at right angles to the dike, causes a foliation of the latter parallel to its elongation. If the stress continues after the recrystallization of the dike has been completed, there is no further metamorphic plasticity, and the rock being now compelled to behave as do its neighbours, a secondary foliation transverse to the dike may develope as we have discussed above.

The foliation of the dikes may in all cases be explained in this way. The exceptional condition of the stress acting in a direction strictly parallel to the dike is probably never realized more than instantaneously, for at different stages of the crustal movement the direction of stress must be somewhat variable.

So far the part played by changes of volume in the rock during metamorphism has not been considered. If the volume is decreased by the transformation, no external stress whatever is needed to produce foliation. In this case, provided the dike-rock is more compressible than the country-rock, the static pressure is resolved into a stress at right angles to the strike of the dike. If, on the other hand, a dilatation of the rock-mass is brought about by the metamorphism, no foliation can result without the action of a regional stress.

According to the well known theories of Becke, Grubenmann and Van Hise, the metamorphism of a rock-mass which has sunk from the upper zones to deeper belts of the lithosphere is chiefly controlled by the volume-law, and of all possible mineral associations, those whose volume is the minimum, are likely to be formed. If a contraction of the volume should really take place generally in rocks whose minerals have been formed near the earth's surface, and afterwards sunk down to deeper regions and metamorphosed, the conversion of the static pressure into stress normal to sill-like rock-masses would indeed be an important factor in rock-metamorphism. In the case of amphibolites, however, contraction can scarcely have taken place (cf. p. 130).

Diopside-amphibolites.

A group of amphibole-bearing rocks which occurs over wide areas within he leptite region may be described as diopside-amphibolites. Except that they have amphibole as an ordinary constituent these rocks have very few features in common with the amphibolites described above. They occur as sheet-like masses, but they are frequently intercalated with thin layers of leptite. Even when occurring as thicker layers, they show a sort of miniature bedding and have individualized layers each composed of a special material (fig. 21).

The more important constituents of these rocks are hornblende, diopside, plagioclase and microcline, the two last named occurring in approximately equal amounts. Calcite is an important accessory and titanite is always present in small amount. As a consequence of the heterogeneous nature of the rock, the quantitative mineralogical composition is quite variable. Sometimes microcline is absent.

Layers devoid of diopside are frequently met with and the rock may then be mineralogically identical with some of the normal amphibolites. The general mineralogical composition of the diopside-amphibolites shows, however, that they have quite a different set of chemical characters and must be considerably richer in lime than the amphibolites proper.

All these features point to the suggestion that the diopside-amphibolites are of a sedimentary origin and that they have originated by the alteration by metamorphism of a series of calcareous shales, probably mingled with volcanic materials.

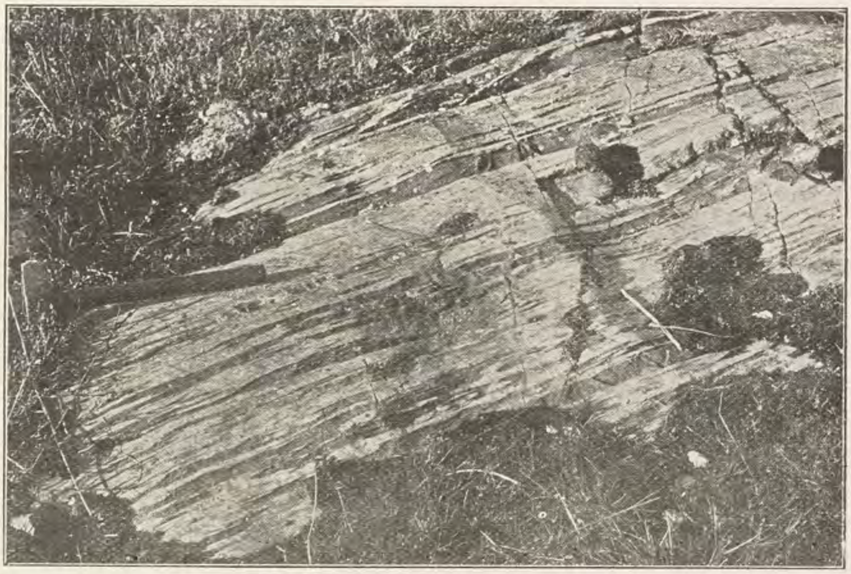


Fig. 21. Diopside-amphibolite. The paler bands contain abundant diopside, while the dark lenticles are rich in hornblende. Near Ilves, Toija, Kisko.

The distribution of the diopside-amphibolites may be seen from maps I and II. In general they seem to belong to a continuous zone which extends from the regions north of Lake Orijärvi to Lake Kiskon Kirkkojärvi. Farther where the general strike of the schists turns in a southwesterly direction, the continuation of this zone is again found south of the last-named lake.

The diopside-amphibolites occur in typical form in the hills west of the road from the Orijärvi mine to the village of Vetjo. The bedding is usually well marked, pale diopsidic layers alternating rather regularly with duller layers rich in amphibole, some centimeters in thickness. Here and there the alternation is on a smaller scale and at some places it disappears entirely.

These homogeneous diopside-amphibolites contain diopside, hornblende, plagioclase, microcline, calcite, titanite and apatite.

The diopside forms large skeletal individuals (pl. II, fig. 6), often a few millimeters in diameter, elongated along the strike of the rock. Parts of the crystals appear in the slice as globular grains sometimes completely isolated from each other, and forming a part of the hornfels mass. They have a strictly parallel arrangement, a fact which proves that all are parts of some larger individual. The main part of the crystal is usually more compact, and grains of plagioclase and microcline occur as inclusions. Prismatic as well as basal cleavage-cracks are dinstinct. The crystals are optically positive; the extinction angle $c : \mathfrak{c} = 54°$. The colour is pale green and there is no visible pleochroism. These properties make it probable that this pyroxene belongs to the diopside series and contains some 50 % hedenbergite.

The h o r n b l e n d e is of the common green type, occurring partly as small idioblastic prisms, and partly as rounded grains which have forms quite identical with those of the diopside, they too being portions of large individuals. As such grains of hornblende are arranged all round the diopside individuals it is quite evident that they are really pseudomorphs after the latter.

P l a g i o c l a s e occurs only in the hornfelsic ground-mass and as very small grains. Twinning of the albite-type is rarely present. The maximum extinction angle in sections $\perp$ (010) is 34°, indicating a mixture of about $Ab_{40}An_{60}$.

M i c r o c l i n e, somewhat less in amount than the plagioclase, is contained in the hornfels mass as minute grains without any twinning, and occurs also as large cross-hatched xenoblasts, in which small grains of plagioclase are intergrown.

C a l c i t e forms irregular xenoblasts, often in diablastic intergrowth with the pyroxene.

T i t a n i t e is found as small euhedral crystals showing nothing that would indicate that it were formed from ilmenite. A p a t i t e, on the other hand, occurs as quite anhedral grains.

In other specimens still more calcic plagioclases have been observed, up to $Ab_{85}An_{15}$. In this respect the diopside-amphibolites are essentially different from the other amphibolites in which no such calcic plagioclases occur. This circumstance is in agreement with the high total amount of lime in the rock. To this same fact is due also the occurrence of diopside which could not be uralitized, since all the available magnesia and ferrous iron had been used up to form hornblende. Characteristically biotite is absent.

The diopside-amphibolites are analogous to the plagioclase-diopside-hypersthene-hornfels from the Christiania region [1] (class 6 of Goldschmidt), but in our rock hornblende has been formed instead of hypersthene (+ part of diopside).

The genesis of the amphibolites.

Geological and petrographical facts make it evident that except the diopside-amphibolites the amphibolites described above are metamorphosed igneous rocks. In one case a change of composition is suspectible (p. 113). Away from such special regions there is nothing to indicate that the total composition of the rock has been altered. To each analysis of amphibolite a parallel can be found among the analyses of igneous rocks which shows no differences greater than those which are known among the multitude of igneous rocks themselves.

The following table (XIX) makes this evident. Some analyses of amphibolites from the Fenno-Scandian Archaean and their correlates among igneous rocks are there placed along side. The odd numbers refer to amphibolites, the even numbers to igneous rocks. For the amphibolite near the Workmen's Association, Orijärvi, several parallels have been quoted, chosen from rocks which have rather various mineralogical compositions. These will be the subject of further discussion.

It may first of all be observed that the igneous rocks represented by the analyses given in the table are almost all of supercrustal origin, as most probably originally were also the amphibolites.

The composition of the amphibolites is quite certainly p o s s i b l e for igneous rocks, and if the amphibolites were melted and resolidified under volcanic conditions, the minerals formed would be those which are now found in these igneous correlatives. T h e c o n v e r s i o n o f t h e s e m i n e r a l s i n t o p l a g i o c l a s e a n d a m p h i b o l e w i t h s o m e s m a l l a m o u n t o f t i t a n i t e o r i l m e n i t e c a n b e r e g a r d e d a s d u e t o i n t e r n a l r e a d j u s t m e n t s b y m u t u a l c h e m i c a l r e a c t i o n s w i t h i n t h e m s e l v e s. Analysis 1, of the dolerite from Mount Ingalls, Plumas County, California (2 a), according to Turner (l. c.), is nearly or quite holocrystalline, consisting of lath-

[1] V. M. Goldschmidt, »Die Kontaktmetamorphose im Kristianiagebiet», p. 173.

Table

	1.	2 a.	2 b.	2 c.	2 d.	2 e.	3.	4.
SiO_2	52.98	52.81	50.89	51.36	51.98	51.32	52.39	52.60
Al_2O_3	17.49	16.60	16.76	16.25	15.99	15.28	17.56	17.32
Fe_2O_3	0.54	2.66	3.86	2.14	3.10	0.47	1.33	1.72
FeO	6.39	6.13	4.69	8.24	5.88	8.59	11.27	12.04
MnO	0.13	—	0.13	0.09	0.10	0.16	—	—
MgO	6.00	6.12	8.49	7.97	5.09	7.25	4.87	3.25
CaO	11.33	10.14	11.72	10.27	9.68	11.58	8.84	7.73
BaO	—	0.03	—	—	0.03	—	—	—
Na_2O	3.16	2.79	2.61	1.54	2.71	2.92	2.18	2.62
K_2O	0.31	1.05	0.32	1.06	0.81	0.22	0.60	1.49
TiO_2	0.78	0.84	0.79	—	1.71	1.23	0.72	—
P_2O_5	—	0.23	0.09	—	0.31	0.25	—	0.15
CO_2	—	—	—	—	—	—	—	0.14
S	—	—	—	—	0.01	—	—	—
H_2O	0.57	0.92	0.41	1.33	2.56	1.01	0.87	1.16
	99.68	100.32	100.76	100.28	99.96	100.28	100.63	100.22
				Incl. 0.03 % NiO				

1. Amphibolite, Orijärvi (page 100).
2 a. Dolerite, Mount Ingalls, Plumas County, California. Analyst W. F.
2 b. Basalt, Inskip Crater, Lassen Peak, California. Analysts W. H.
2 c. Basalt, Watchung Mountain, Orange, New Jersey. Analysts L. G.
2 d. Olivine-diabase, Camas Land, Kittitas County, Washington. Ana-
2 e. Diabase, Hornitos, Mariposa County, California. Analyst W. F. Hille-
3. Amphibolite, Liipola, Kisko (page 104).
4. Lava, Eycott Hill, Lake District, England. Analyst J. Hughes.
5. Amphibolite, dike in limestone, Lammala, Westanfjärd, Finland.
6. Orthoclase-gabbro, Duluth, Minnesota, analyzed and described by
7. Amphibolite, dike in limestone, Tytyri, Lohja, Finland. Analyst
8. Basalt, Kyrburg, Nahethal Rh. Preussen. Analyst Bärwald, K. A.
9. Amphibolite, Valboskär near Utö, Sweden. Analyst R. Mauzelius.
10. Basalt, Lava of May 1883, Kilauea, Hawaii, analyzed and described
11. Amphibolite, West of Ormbergstjärn, Grängesberg, Sweden. Ana-
12. Basalt, Krötenkopf, Hesse. Analyst H. Wolff. K. Oebbeke. Jb. Pr.
13. Amphibolite, Spikarna, east of Hangö, Finland. Analyst P. Eskola.
14. Andesite, Sierra de Mareveles, Luzon, P. I. Analyst Oebbeke. Quo-

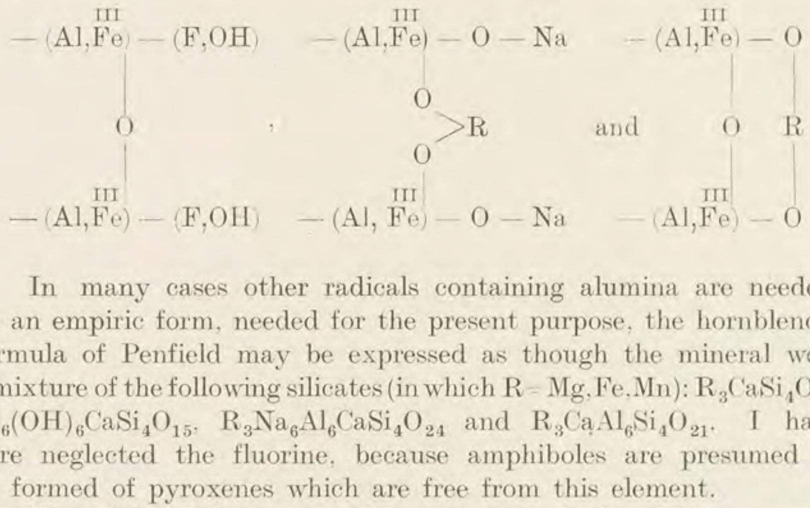
XIX.

5.	6.	7.	8.	9.	10.	11.	12.	13.	14.
53.75	52.48	54.17	52 16	48.90	49.20	49.68	49.97	54.67	54.62
16.10	15.47	16.15	15.86	14.19	14.90	16.40	16.38	16.69	16.96
6.36	5.14	2.70	4.90	3.50	4.51	3.46	3.62	1.41	4.50
6.38	9.25	8.83	5.86	11.85	12.75	7.50	6.76	7.57	4.27
0.27	0.51	0.22	—	0.20	0.28	0.32	—	0.17	0.35
4.53	2.55	4.81	4.57	5.72	3.90	6.20	7.50	4.41	5.20
6.53	7.27	7.91	8.16	9.14	9.20	10.14	8.95	8.23	8.56
—	—	—	—	0.01	—	—	—	0.10	—
3.81	3.26	3.02	3.67	1.09	1.96	3.00	3.22	3.08	3.26
1.62	1.75	0.65	0.88	0.87	0.95	1.12	1.55	1.78	1.80
—	1.26	—	0.32	2.40	1.72	0.70	—	1.12	tr.
—	0.29	—	0.24	0.41	0.42	0.09	—	0.29	—
—	—	—	1.38	—	—	—	—	—	—
SO_3 0.09	—	0.61	0.21	S 0.40	—	—	—	0.07	—
1.18	1.24	1.04	2.28	1.21	0.10	1.52	2.18	0.95	0.73
100.62	100.47	100.11	100.54	99.89	99.89	100.13	100.19	100.54	100.25
	Sp. g. 2.83		Sp. g. 2.764				Sp. g. 2.84		

Hillebrand. H. W. Turner, 14 A. R. U. S. G. S., II, p. 492, 1894.
Hillebrand and Chatard. J. S. Diller, B U. S. G. S., 148, p. 200, 1897.
Eakins, J. P. Iddings, B. U. S. G. S., 150, p, 225, 1898.
lyst H. N. Stokes. G. O. Smith, B. U. S. G. S., 168, p. 225, 1900.
brand. H. W. Turner, J. G. III, p. 403, 1895.

Ward, Micr. Journ., 1887, p. 246 ff.
Analyst N. M. Slawsky. P. P. Sustshinsky, op. cit. (41) p. 64, 1912.
A. N. Winchell. A. G. XXVI, p. 293, 1900.
N. M. Slawsky. P. P. Sustshinsky, op. cit. (41) p. 6, 1912.
Lossen, Jb. Pr. G. L.-A., X, p. 309, 1892.
P. J. Holmquist, G. F. F., April 1910, table of analyses n:o 17.
by A. Silvestri. B. C. G. It., XIX, p. 135, 1888.
lyst Grabe. H. E. Johansson, G. F. F. 32, p. 314, 1910.
G. L.-A. IX, p. 393, 1889.
Not published before.
ted from Iddings, Igneous rocks, II, p. 214, 1913.

shaped plagioclase, with augite and magnetite, and with abundant hypersthene. In the specimen analyzed there was scarcely any olivine. Apparently this composition is nearly normative, only augite being present instead of diopside. As the augites generally contain only a small percentage of alumina, this difference is of no great importance. We may therefore begin by regarding the normative composition as a possible composition for amphibolite 1. In order to interpret the change of this combination of minerals into the modal composition, a convenient formula for hornblende elastic enough to comprise all variations of this mineral must be found. At the present time the most trustworthy interpretation of the composition of monoclinic amphiboles is perhaps the one given by Penfield and Stanley[1]. According to these authors all amphiboles of the actinolite-hornblende-series may be considered as metasilicates of the type $\overset{II}{R}_3CaSi_4O_{12}$, where Si may, to some extent, be replaced by Ti and $\overset{II}{R}$ is Mg, Fe, Mn, Na_2, K_2, H_2 and one or several radicals of the following types:



In many cases other radicals containing alumina are needed. In an empiric form, needed for the present purpose, the hornblende-formula of Penfield may be expressed as though the mineral were a mixture of the following silicates (in which R = Mg,Fe,Mn): $R_3CaSi_4O_{12}$, $Al_6(OH)_6CaSi_4O_{15}$, $R_3Na_6Al_6CaSi_4O_{24}$ and $R_3CaAl_6Si_4O_{21}$. I have here neglected the fluorine, because amphiboles are presumed to be formed of pyroxenes which are free from this element.

The origin of these molecules, present in the hornblende, can be expressed by the following equations:

1) $2RSiO_3 + RCaSi_2O_6 = R_3CaSi_4O_{12}$.

2) $3CaAl_2Si_2O_8 + 3H_2O + 6RSiO_3 = CaAl_6(OH)_6Si_4O_{15} + 2CaR_3Si_4O_{12}$.

3) $2RSiO_3 + RCaSi_2O_6 + 6NaAlSi_3O_8 = R_3Na_6Al_6CaSi_4O_{24} + 18SiO_2$.

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[1] *Am. J. Sc.* 28, p. 23, 1907.

4) $9RSiO_3 + 3CaAl_2Si_2O_8 = R_3CaAl_6Si_4O_{21} + 2R_3CaSi_4O_{12} + 3SiO_2$.

Furthermore, the following reactions must be supposed, to eliminate the magnetite and the ilmenite of the norm:

5) $FeOFe_2O_3 + RCaSi_2O_6 + RSiO_3 + SiO_2 = R_2FeCaFe_2Si_4O_{15}$

6) $FeTiO_3 + CaMgSi_2O_6 + SiO_2 = CaTiSiO_5 + MgFeSi_2O_6$.

In the present case the calculated composition of the amphibole, if 0.6 % H_2O are supposed to be present, agrees approximately with Penfield's formula, giving 92 molecules of the first, 5 molecules of the second, 3 of the third and none of the fourth silicate, the absence of this silicate being in accord with Penfield's conclusions with regard to actinolites. Thus reaction 1) is by far the most important here. As the proportion of water and alkalis in common hornblendes is never very much greater than was assumed in this amphibole, the quantitative importance of reactions 2) and 3) is always comparatively slight. Both transfer alumina into the amphibole and diminish the amount of plagioclase, in one case albite, in the other anorthite, the mean composition of the residual feldspar being little changed. On the other hand, if more aluminous amphiboles are formed, considerable amounts of anorthite must be destroyed and the remaining plagioclase must be more albitic in accordance with equation 4). The composition of hornblendes from n o r m a l contact-metamorphic rocks is still very little konwn. There is, however, no doubt that highly aluminous hornblendes also exist in them (cf. the calculated composition of hornblende page 104 and the analysis of hornblende page 110). As pyroxenes from igneous rocks are always low in alumina, this compound must have been derived from the plagioclase, provided, of course, that no hornblende was present in the original rocks. This is in accordance with the fact that in amphibolites the mean plagioclase, so far as my experience goes, is never more calcic than a labradorite bytownite, while in igneous rocks rich in monoclinic and orthorhombic pyroxenes bytownite and anorthite are of common occurrence.

In equations 5) an 6) the fact that amphibolites are generally free from iron ores, ordinarily met with as accessories in igneous rocks, is mentioned. Reaction 6), however, does not always take place, as ilmenite is sometimes found. The direction of this reaction is controlled by the mass-effect; where diopside is in excess of the ratio necessary for the amphibole molecule, titanite results, in other cases ilmenite remains.

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[1] Analyses of amphiboles from pneumatolytic formations, such as the skarn, can hardly be used for comparison.

Returning to the discussion of analysis 1 let us suppose that the original rock contained plagioclase, hypersthene and iron ores as before, but with augite instead of diopside. The composition would then actually be that of the dolerite from Mount Ingalls (analysis 2 a). As augite already contains silicates of the type $RAl_2Si_2O_6$, the change of pyroxenes into amphibole is chiefly due to the combination of hypersthene and diopside silicates according to equation 1). In general, however, it is probable that the amphibole contains more alumina than the original augite, the excess having been derived from plagioclase, chiefly according to equation 4). Other possible sources of alumina, hitherto unconsidered, are chlorite and epidote. But as these minerals occur in igneous rocks only as products of the alteration either of plagioclase or of mafic minerals, their alumina comes originally from the same common source.

The basalt from Inskip Crater, Lassen Peak, California (analysis 2 b), consists, according to Diller, of plagioclase, pyroxene and olivine. The same constituents are met with in the olivine-diabase from Camas Land, Kittitas County, California (analysis 2 d), which G. O. Smith (l. c.) has found to contain augite, olivine, plagioclase, magnetite and apatite. In the basalt from Watchung Mountain, Orange, New Jersey (analysis 2 c), a small amount of glassy base is present. The holocrystalline compounds are described by Iddings (l. c.) as follows: Pyroxene and plagioclase besides magnetite, serpentine and chlorite are the main constituents. Pyroxene, in excess of plagioclase, probably labradorite, is malacolite. It is probable that olivine was present in the rock before decomposition set in. A few crystals of this mineral have been observed.

These rocks, all of which consist chiefly of plagioclase, pyroxene and olivine, contain nevertheless silica in excess of the metasilicate ratio, i. e. quartz appears in the norm: [1] Consequently the formation

[1] This case which is really very common, deserves some attention, being seemingly in conflict with the generally accepted theory that olivine can only crystallise when a deficiency of silica excludes the formation of the metasilicate minerals. The question might be asked: In which form does the excessive silica exist? Where glass is present, silica may be contained in it, but in holocrystalline rocks, such as the olivine-diabase from Camas Land, this fact can hardly be understood unless quartz were actually present. In the analyses of pyroxenes no excess of silica appears. As pyroxenes always contain certain amounts of alumina, soda and potash, the percentage of the acid feldspar silicates is actually lower than in the norm, or the amount of free silica would be still larger. This is balanced, to some extent, by the fact that the compounds of magnetite in the norm may actually enter into the pyroxene-molecule, whereby silica, equivalent to the amount of FeO, is bound

of amphibole from olivine or pyroxene + silica is possible throughout and may be expressed by the equations given above, except that $R_2SiO_4 + SiO_2$ must be written instead of 2 $RSiO_3$. But if there was not a sufficient excess of silica present in the original rock, silica may partly be derived from the feldspars according to equations 3) and 4). Moreover, it is probable that hornblendes exist which have a larger deficiency of silica below the metasilicate ratio than can be expressed by the formulas used above. Penfield himself (l. c.) points out that more basic radicals containing alumina and monoxides may be needed in certain cases.

The diabase from Hornitos, Mariposa County, California, consists according to Turner (l. c.) of augite and hornblende, apparently intergrown, in which are imbedded feldspar laths. In another paper [1] the same rock is described as containing labradorite, augite and magnetite, sometimes biotite. Provided the rock contained augite showing the ratio (Fe,Mg) : Ca″ = 1 : 1 (Ca″ = Ca contained in the femic minerals), its conversion into amphibole would be impossible, as will be shown. But the analysis proves clearly that the pyroxene must be considerably poorer in lime, the ratio (Mg,Fe) : Ca in the femic compounds being 303 : 106, i. e. almost exactly that of the amphibole molecule. It therefore seems probable that the pyroxene of this rock was really an enstatite-augite, whose common occurrence in diabase, long suspected by Rosenbusch, was proved by W. Wahl [1] and confirmed by the investigations of H. Backlund [2] and others. Thus the reactions which give rise to hornblende may in this case also be expressed by the equations given above.

On studying a larger collection of analyses of diabasic and gabbroid rocks, it will soon be found that a ratio (Mg,Fe) : Ca″ within the limits usual in hornblendes is remarkably frequent. In all such cases the formation of the hornblende during metamorphism

to form metasilicate, but this amount does not generally suffice to eliminate the silica in excess of the metasilicate ratio. And still larger amounts of silica are liberated by the formation of the orthosilicate-molecules. As, however, numerous rocks described as olivine-bearing, when analyzed by the ablest chemists, show an amount of silica more than sufficient to form metasilicate with the present bases, the conclusion seems inevitable that such rocks, when holocrystalline, must contain considerable amounts of quartz. It is well known that very acid rocks may contain fayalite. On the other hand, small amounts of quartz are frequently mentioned in descriptions of olivine-diabases.

[1] H. W. Turner, **17** *A. R. U. S. G. G.*, I, p. 694, 1896.

[1] »Die Enstatitaugite», *T. M. P. M.* **26**, 1, 1907 and: »Die Gesteine der Westküste des Onega-sees», *Fennia* **24** N:o 3, 1908.

[2] »Über einige Diabase auf arktischem Gebiet», *T. M. P. M.* **26**, 357, 1907.

can be explained as being essentially due to interreactions among the femic compounds. In such cases the plagioclases in the amphibolite may retain their original composition. Cases in which the lime is present in excess of the above ratio, are unusual. Of 125 analyses of hessoses and auvergenoses quoted in Washington's tables, only 7 have such an excess of lime. All are infracrustal rocks and most of them, in one way or another, abnormal (»light bands» in gabbro etc.). In this case not all the pyroxene can possibly be converted into amphibole, unless the other products are different from those in the amphibolites under consideration. Excess of Ca″ in the pyroxene cannot be driven over into plagioclase (or epidote), unless there are external sources of alumina to correspond. Thus the derivates of these rocks, when metamorphosed under such conditions as have prevailed in our area would of necessity be pyroxene-bearing. Diopside-amphibolites, containing in fact such excessive lime, occur here in large proportions. It makes no difference that these rocks are probably of a sedimentary origin. Of foreign occurrences we need only mention the augite-plagioclase-fels (»Erlan-fels»). An analysis of the »Erlan-fels» from Erlahammer, Schwarzenberg, Saxony [1] gives the ratio (Mg,Fe)O : CaO″ = 1.49 : 1. Apparently any perfect conversion of the augite into hornblende is here excluded.

Rocks with more (Mg,Fe) than is required to satisfy the hornblende ratio are very common among those igneous rocks in which olivine or hypersthene is developed along with a calcic plagioclase. When such rocks are converted into amphibole-plagioclase-rocks, one of two sets of minerals must occur. Either the resulting amphibole will be in part a ferro-magnesium amphibole (i. e. cummingtonite or anthophyllite) or lime will be derived from the anorthite to form hornblende. If no excess of silica is present, the former alternative is impossible. The presence of cummingtonite in the Orijärvi amphibolite has been recorded above, but it is not quite certain that the composition of this rock is unchanged. In normal metamorphic rocks, so far as is known to the writer, the presence of cummingtonite has not been proved. As the optical properties of this mineral are nearly identical with those of actinolite, it is possible that the former might have been taken for the latter. Actinolite and tremolite are in fact frequently described as products of alteration of olivine, but the identity of those colourless amphiboles has not been established by chemical analyses. Consequently, it cannot at present be decided

[1] U. Grubenmann, »Die Kristallinen Schiefer», p. 210, 1910. — All iron present is calculated as ferrous oxyde.

whether or not a conversion of olivine and ferro-magnesium pyroxene into monoclinic ferro-magnesium amphiboles really does take place by the normal metamorphism, but the possiblity of such a change should not be over-looked.

On the other hand, common green hornblende is certainly frequently formed by reaction between pure ferro-magnesium silicates and anorthite. In such reactions much alumina derived from the anorthite must enter into the composition of the resulting hornblende, and it is probable that the amphiboles occurring in amphibolites poör in feldspar, are highly aluminous (cf. p. 105). If the original proportion of feldspar was low, it may become exhausted and the formation of a hornblendite may result. If excess of (Mg,Fe-) minerals beyond this proportion is present, there is nothing with which the last portion can react, and a metamorphic hornblende-peridotite will be formed from a rock which originally had the mineralogical composition of a gabbro. The peridotite from Pyhälampi, described above, is free from feldspar, but plagioclase is present in many of its non-metamorphosed correlatives, as e. g. the gabbro from Rosswein, Saxony.

As already mentioned, the plagioclase of igneous rocks which are rich in ferro-magnesian compounds is generally a very calcic variety, whereas in corresponding amphibolites it is a labradorite or andesine. If all the plagioclase is exhausted in the making of amphibole, the small amount of soda must also have entered into the composition of the hornblende. Potash, on the other hand, generally goes to form biotite.

If this theory of the origin of amphibole is right, it may also be applied to the case of u r a l i t i z a t i o n in those cases in which the crystalline forms are preserved. The change would then consist essentially of an addition of hypersthene to the diopside molecules to form actinolite. The process cannot, however, in reality be one of simple addition. The fact that the individuality, structure and twinning of the original pyroxene is often preserved, proves that a true molecular substitution must have taken place. The reaction may be expressed by the following equation:

$$Ca_2Mg_2Si_4O_{12} + MgSiO_3 = CaMg_3Si_4O_{12} + CaSiO_3.$$

This reaction may be explained as follows: A molecule of hypersthene is brought into solution and wanders until it is in contact with diopside. The more stable actinolite molecule is formed and takes the place of a double diopside molecule, while a wollastonite molecule, in solution, wanders out until it meets new hypersthene to form actinolite. As a matter of fact, groups and fringes of actinolite prisms surrounding uralites are of common occurrence.[1]

The pale colours usual in uralite seem to indicate that the resulting amphibole is in reality of an actinolitic composition, containing probably only that alumina which was originally present in the augite. In certain cases, as shown by Duparc and Hornung for the uralite-gabbro of Cerebriansky, Ural, alumina is present in large amount. It must then be derived from plagioclase.

An important question is that concerning the change of volume during the metamorphism. I calculated the specific gravity of that theoretical rock wlich has a composition identical with that shown in analysis 1 (p. 122) and whose mineralogical composition is normative. A comparison with the specific gravity of the amphibolite led to the result the volume should have remainad practically unchanged during metamorphism. A few other calculations gave the same result, or showed a slight increase of the volume. The water contained in the amphiboles was assumed to have been present as inclusions in the original rock and to have had the sp. g. 1.

It seems therefore probable that no contraction of the volume has taken place in the case in question. The writer regards, however, the determinations so far made as insufficient, and the results will not therefore be published in full before more evidence has been afforded.

[1] J. J. Sederholm, »Studien über archäische Eruptivgesteine aus dem südwestl. Finnland», *T. M. P. M.*, **12**, p. 104, 1891.

O. Nordenskjöld, »Ueber archaeische Ergussgesteine aus Småland», *Bull. Geol. Inst. of Upsala*, I, p. 201, describes a plagioclase-uralite-porphyrite, where the hornblende is surrounded by a secondary colourless amphibole, considered to be tremolite.

R. Beck, *T. M. P. M.*, 13, p. 326, mentions uralitic hornblende growing at the expense of the surrounding plagioclase, around the primary augite crystal.

Cf. further: Rosenbusch. »Mikr. Phys.», II, 2, p. 1179 (1908). The suggestion of Rosenbusch that the excessive lime from the pyroxene would be transferred into the epidote cannot be right.

[1] *Compt. Rend. de l'Ac. Sc. Paris*, **139**. p. 223, 1904. The theory of the origin of the uralite proposed by these authors cannot be applied to amphibolites of supercrustal orgin, such as those of the area in question.

The leptites.

The term leptite will here be used in the sense defined by the Swedish geologists who adopted this word in preference to the numerous synonyms, such as »eurite», »hälleflintgneiss» or »granulite» [1], to signify those aphanitic or fine-grained metamorphic Archaean rocks which are composed mainly of quartz and feldspars with subordinate amounts of coloured minerals. The proportion and composition of the feldspars varying considerably, the bulk composition of the leptites also varies between wide limits. The variable composition is also responsible for differences in the minor constituents, of which muscovite, biotite and hornblende are common, and almandine and cordierite are not infrequent. In the mode of their origin, too, the leptites are greatly various. The inclusion of so many essentially different rocks under this collective term is justified only by the difficulty of recognizing the differences without detailed chemical or microscopical examination.

The leptites of southwestern Finland show many close analogies to the leptites of Sweden in which country they have been studied in great detail by A. E. Törnebohm, Hj. Sjögren, H. Bäckström, O. Nordenskjöld, P. J. Holmquist, H. E. Johansson and others. In Finland petrographical description of these rocks has not yet been undertaken.

On our maps we have divided the leptites into two groups: (1) the b l a s t o p o r p h y r i t i c l e p t i t e s and (2) the e v e n-g r a i n e d l e p t i t e s. The former group comprises rocks which have readily recognizable phenocrysts of quartz set in a fine-grained ground-mass. When not greatly changed by metamorphism, phenocrysts of feldspar are also evident. This group is believed to represent metamorphosed porphyritic rocks. In the second group we include all those leptites, which have a thoroughly fine-crystalline texture.

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[1] A. G. Högbom, »Om om en ändring af nomenklaturen för våra granuliter och hälleflintgneiser», *G. F. F.* 30, 1908. Discussion on the same subject ibid.

These rocks are believed to be partly of igneous, partly of sedimentary origin. In many cases it is impossible to determine their origin with any certainty.

Cordierite-leptite and phyllite have been separated from the leptites proper. Both these have the composition of argillaceous sediments.

By increase in the coarseness of their texture the leptites pass gradually into gneissic rocks. Such rocks not being genetically different from the leptites, have been termed leptitic gneiss.

Certain leptitic rocks which show fragmental structure have been termed agglomeratic leptites.

The blastoporphyritic leptites.

The best preserved quartz-porphyritic rock within the leptite area occurs south of the village of Lapinkylä in Kisko. This rock shows phenocrysts of feldspar and quartz in a dense red-coloured ground-mass. A specimen from this locality was analyzed by Mr. O. Stenberg with the following results (table XX).

Table XX.

		Mol. prop.	Mol. %	Norm		Mode	
SiO_2	74.50	1.242	80.8	Q	41.10 %	Quartz	45.1 %
Al_2O_3	12.11	.119	7.7	Or	20.02	Microcline	10.0
Fe_2O_3	0.59	.004		Ab	21.48	Albite	21.5
FeO	2.81	.039	3.1	An	3.89	Anorthite	3.1
MnO	0.05	.001		Cor	2.86	Biotite	16.9
MgO	1.35	.034	2.2	Σ sal	89.35	Titanite	0.6
CaO	0.76	.041	0.9	Hy $MgSiO_3$	3.40		97.2
Na_2O	2.55	.041	2.7	Hy $FeSiO_3$	4.36	Al_2O_3	1.6
K_2O	3.39	.036	2.4	Mt	0.93	H_2O+	0.6
TiO_2	0.27	.003	0.2	Il	0.46	H_2O-	0.4
P_2O_5	0.05	.000	—	Σ fem	9.15		99.8
H_2O+	0.95	—	—		98.50		
H_2O-	0.38	—	—				
	99.76		100.0				

Tehamose.

Osann's system:	s	A	C	F	n	a	c	f	k	T
	81.0	5.1	0.9	5.3	5.3	9.0	1.5	9.5	2.41	1.7

The mode was calculated from the analysis on the assumption that all the magnesia and the iron are present in a biotite of the composition $KHAl_2(SiO_4)_2 \cdot (Mg,Fe)_2SiO_4$. Furthermore it was assumed that all the titanium dioxide enters into the titanite which is visible as globular grains or groups.

The mean composition of the plagioclase is $Ab_{88}An_{12}$, according to the calculation based on the chemical analysis. This mineral was observed only as phenocrysts. Under the microscope the plagioclase shows a maximum extinction angle of 9°, having $\gamma_1 < \omega$ which should indicate the composition $Ab_{87}An_{13}$. The clear borders of the greatly altered crystals are often more albitic, up to pure Ab.

The large amount of Al_2O_3 and H_2O remaining after the calculation of the minerals must be due to the abundant alteration products within the phenocrysts. Of these products, only muscovite occurring as distinct scales can be determined. Chlorite is occasionally visible in the ground-mass and calcite occurs in traces.

The chemical composition of this rock is one commonly met with in granites and, especially, in liparites and rhyolites. The large excess in alumina is a feature very common in the tehamoses, both in phanerites and aphanites. Thus we have no reason for assuming any considerable change in the bulk composition of this rock, and its texture proves with certainty that it was originally a volcanic rock.

In this rock phenocrysts of quartz, plagioclase and microcline are embedded in a granoblastic ground-mass, made up chiefly of quartz, biotite and microcline (pl. III, fig. 1). Plagioclase could not be detected in the ground-mass. This is in fact very remarkable, as the greatest part of the phenocrysts consist of plagioclase. It seems that nearly all the soda had been taken up in the phenocrysts. These are from 1 to 3, rarely 5 mm in diameter, and the grains of the ground-mass which are very constant in size average 0.02 mm. Only the microcline shows a tendency to assume larger dimensions.

The phenocrysts of q u a r t z are rounded and show the characteristic phenomena of corrosion well known in liparites. Euhedral bipyramidal forms were also met with. The outlines are always fringed, due to the secondary growth of the ground-mass. Mechanical deformations have left their record in the distinct strain shadows and in a partial crushing of some of the grains.

The feldspar phenocrysts consist in most cases of p l a g i o c l a s e. They are also of the type usually met with in liparites, being sometimes euhedral but more often fragmental, and bounded by cleavage faces. Incipient granulation beginning from the borders is often visible.

M i c r o c l i n e is intergrown with the plagioclase phenocrysts forming portions with irregular outlines and having the plane (010) in common with the matrix individual. Many of the phenocrysts are surrounded by microcline in similar arrangement, or as granulated masses. Microcline also forms a few phenocrysts which are free from plagioclase. It is always cross-hatched.

The ground-mass shows a distinct schistosity, due to a parallel arrangement of the minute scales of pale brown biotite.

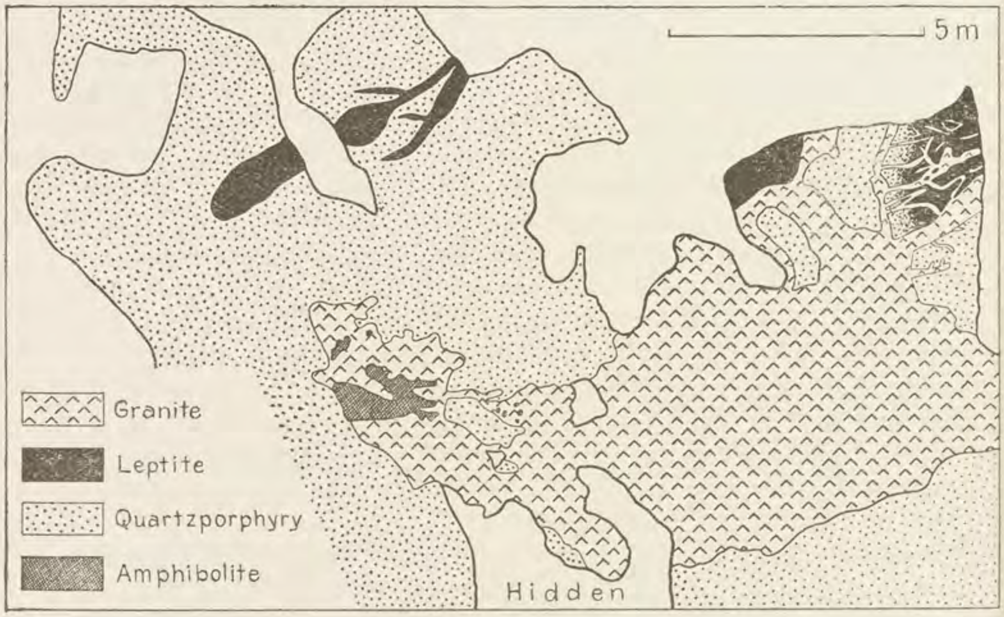

Fig. 22. Quartz-porphyry in contact with the oligoclase-granite. West of the road near the southernmost point of Kiskon Kirkkojärvi, Lapinkylä, Kisko.

In the analyzed rock almost no traces of metamorphism can be seen with the naked eye. At this locality the phenocrysts are red-coloured, as also is the ground-mass. From this type there are all possible degrees of transition into schistose rocks which resemble mica-schists, in which no feldspar phenocrysts can be seen, and the quartz-phenocrysts appear only as very thin lenses. Such a rock occurs within less than half a km of the above locality, in the village of Lapinkylä, where it is seen in contact with the dense and even-grained leptites, with agglomerates, diopside-amphibolites etc. Near the boundary, as for instance at the silver-mine of Aijala, the blastoporphyritic leptite is intercalated with beds of even-grained leptite.

The geological relations of this rock to the oligoclase-granite are evident at its contact south of the most southern point of Lake Kiskon Kirkkojärvi. A part of the outcrop is illustrated by fig. 22.

The oligoclase-granite is grey, medium- and even-grained, somewhat finer than usual and contains (in order of their abundance): plagioclase ($Ab_{69}An_{31}$) quartz, biotite, hornblende, microcline, epidote, titanite, apatite. It is speckled with frequent dark fragments, a few cm in diameter, which are rich in hornblende and contain all the other minerals characteristic of the granite. This rock, a part of the large batholith of oligoclase-granite, intersects the metamorphic quartz-porphyry, as is shown in the sketch-map.

The quartz-porphyry is grey in colour, with a granoblastic groundmass somewhat coarser than in the analyzed specimen, but containing the same minerals; its phenocrysts are of quartz, albite-oligoclase and occasional microcline. In this rock there are darker coloured sharp-edged fragments, which differ from the main rock only in so much as they contain larger amounts of biotite (cf. page 68). There is also a fine- and even-grained grey leptite which occurs as intersecting veins, but showing at one point a gradual transition into the porphyritic rock (observe the right hand side in fig. 22). A specimen from this point consists of a granoblastic mass, chiefly quartz, plagioclase and biotite, and smaller amounts of green hornblende and apatite. The grains average about 0.07 mm in diameter. No potash feldspar could be detected, but the biotite is as abundant as the plagioclase. The plagioclase is oligoclase, approximately Ab_4An_1, showing $\gamma_1 < \varepsilon$; $\alpha_1 < \omega$; $\gamma_1 > \omega$.

This locality affords sufficient evidence that the blastoporphyritic leptite is o l d e r than the oligoclase-granite. In the following pages we shall have to consider a series of blastoporphyritic rocks which seem to be n e w e r than the oligoclase-granite.

The blastoporphyritic rock from Valkjärvi, Skogböle, Tenala.

Near the Valkjärvi farm, north of the railway-station of Skogböle in the parish of Tenala, there is a great variety of rocks. Grey banded leptites alternate with limestones, and with these is associated an agglomeratic rock, containing fragments og leptite (cf. page 152). All these rocks are cut by a large dike of the porphyritic rock in question. The dike is 5 to 20 m thick, cutting agglomerates, leptites and limestones, approximately at right angles to their strike.

This rock is also seen in contact with the oligoclase-granite, at the southern boundary of the batholith north of Skogböle. The porphyritic rocks is here bounded on both sides by the granite. It does not, however, penetrate far in the granite-mass, but ends off near the boundary of the latter. At one place on the immediate contact, a thin platelike fragment is enclosed within the porphyry (fig. 23), and the latter shows a narrow but distinct endogeneous contact-zone, in which the nodules of quartz become gradually smaller and the colour of the rock is darkened towards the contact-line. This blastoporphyritic rock must therefore have consolidated later than the oligoclase-granite. On the other hand, it is cut by dikes of the newer amphibolite wich also forms dikes in the granite.

A specimen collected from the middle part of the dike was analyzed by the present writer and yielded the results given in table XXI.

The actual mineral composition of this rock was not calculated. The constituents seen under the microscope are, in order of their relative abundance: Plagioclase, quartz, microcline, hornblende, biotite, iron ores (probably ilmenite) and apatite. Zoisite, epidote and chlorite occur as secondary minerals.

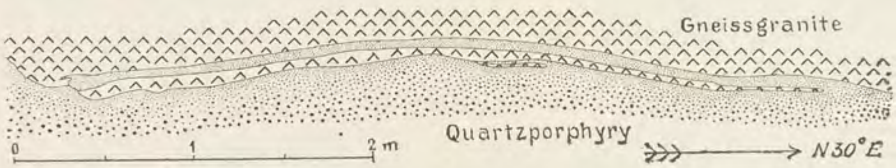

Fig. 23. Porphyritic rock in contact with the oligoclase-granite. Near Valkjärvi, Skogböle, Tenala.

The plagioclase, as calculated in the norm, has the composition $Ab_{56}An_{44}$. It may ben noted, however, that the presence of hornblende and biotite causes the normative anorthite to show a higher percentage than what is actually present in the rock.

The plagioclase grains of the ground-mass show a characteristic and peculiar zonal structure. The mixtures richest in lime form the kernels, as is usual in the primarily zonal plagioclases in igneous rocks, but the transition between the zones is gradual and resembles the inverse zonal structure of crystalloblastic plagioclases. In fact, these ground-mass grains are certainly perfectly granoblastic, showing polygonal forms and only a few thin twinning lamellae of the albite type. The maximum extinction angles found in sections $\perp$(010) and (001) were 30° in the kernels and 14° in the shells, corresponding to the mixtures of $Ab_{46}An_{54}$ and $Ab_{69}An_{31}$ respectively. The more sodic of the plagioclase predominates.

The larger crystals of plagioclase are fairly idiomorphic and have a well developed zonal structure. Often the zones alternate, the most calcic forming narrow rings. These lime-rich zones or inner kernels have entirely altered to epidote or zoisite, which now form large individuals enclosed in the plagioclase. The most albitic outer zones form

Table XXI.

	%	Mol. prop.	Mol. %	Norm	
SiO_2	68.11	1.136	74.4	Q	28.74 %
Al_2O_3	14.40	.141	9.2	Or	18.35
Fe_2O_3	1.03	.006		Ab	22.01
FeO	2.67	.038	3.3	An	18.35
MnO	0.08	.001		Σ sal	87.45
MgO	1.22	.031	2.0	Di $CaSiO_3$	2.09
CaO	4.83	.086	5.7	Di $MgSiO_3$	1.00
BaO	0.12	.001	—	Di $FeSiO_3$	1.06
Na_2O	2.61	.042	2.8	Hy $MgSiO_3$	2.10
K_2O	3.09	.033	2.2	Hy $FeSiO_3$	2.38
TiO_2	0.47	.006	0.4	Mt	1.39
P_2O_5	0.12	.001	—	Il	0.91
S	0.08	.002	—	Ap	0.34
H_2O+	0.57	—	—	Py	0.24
H_2O-	0.17	—	—	Σ fem	11.51
					98.96
	99.57		100.0		

Amiatose.

Osann's system:	s	A	C	F	n	a	c	f	k
	74.8	5.0	4.2	4.8	5.6	7	6	7	1.73

the largest part of the crystals, and in several sections ⊥ (010) and (001) show extinction angles of + 16°, corresponding to $Ab_{66}An_{34}$. The extinction angles found in the most calcic zones attain + 30° corresponding to labradorites with more than 50 % An. Those zones which have been altered to seemingly pure epidote, were originally still more calcic.

Microcline is present only in the ground-mass, were it is subordinate to the plagioclase. Twinning is seen occasionally.

Hornblende occurs principally as large skeletal crystals stained with grains of the minerals of the ground-mass. It is dark green and strongly pleochroic. Brown biotite occurs as thin scales and also in lenticular groupings.

The structure of this rock is not so typically porphyritic as that of the metamorphic quartz-porphyry from Lapinkylä. The smaller grains form a granoblastic ground-mass, the smallest being about 0.03 mm in diameter. But this ground-mass is far from even-grained, and individuals of all sizes, up to one or two millimeters in diameter occur, as well as still larger rounded and granulated nodules of quartz.

Apart from the granulation structure, both quartz and plagioclase bear also witness of mechanical deformation, for bent lamellae and strain shadows are not infrequent.

The rock seems to have been originally holocrystalline, and to have had a fine-grained ground-mass in which large and small idiomorphic crystals of plagioclase were embedded. This is in accordance with its mode of occurrence which is that of a hypabyssal rock.

The composition of this rock is typical of granodiorites, and very similar to that of the Upsala granite (cf. analysis quoted on p. 63). It also resembles that of the oligoclase-granite (p. 41) but differs from it as regards the alkali ratio and the amount of lime. Microscopical examination of the neighbouring oligoclase-granite proved that this granite is here also poorer in lime, for its plagioclase never is more calcic than oligoclase-andesine.

The blastoporphyritic leptites in the Orijärvi field.

A continuous belt of blastoporphyritic leptites is found between the village of Liipola and the farm of Kiimasuo (cf. map II). A specimen from the rock near Liipola shows megascopic phenocrysts of quartz and feldspar. Under the microscope, both these minerals appear as granulated aggregates.

The structure imposed by the granulation of the phenocrysts of plagioclase is very typical (pl. III, fig. 2). The optical properties indicate the composition $Ab_{70}An_{30}$.

No potash feldspar has been observed, but biotite is quite abundant. The total composition of this rock therefore does not differ considerably from that of many examples of oligoclase-granite. The percentage of lime must be considerably lower than in the quartz-porphyritic rock from Skogböle.

In other specimens from this rock-mass the phenocrysts of plagioclase can always be discerned under the microscope but not with the naked eye. Sometimes they have been perfectly granulated, in other cases they have retained their individuality also when so much biotite has been formed in them, that even under the microscope they can only be detected between crossed nicols.

Another belt of blastoporphyritic leptite occurs north of the Orijärvi mine. Near Iilijärvi this belt crosses the contact-metamorphic aureole round the oligoclase-granite and the rock has been considerably changed both in structure and in composition (page 219).

The knotty appearance of the weathered surface is, however, similar to that of the less altered type of these rocks.

Good exposures of the latter type may be found north of the cottage of Auranen, northeast of the mine, and in the forest east of this locality. The rock contains large grains of quartz in a fine-crystalline granoblastic ground-mass. In most cases no large feldspar crystals can be detected, even under the microscope; this is especially the case with the microcline-bearing varieties.

A specimen from the woods north of Perheentupa was found to be composed of quartz, plagioclase, biotite and some muscovite. The plagioclase showed, in a section $\perp$ (010) and (001), an extinction angle of + 14°, corresponding to $Ab_{68}An_{32}$. Thus the rock has probably a composition nearly identical with that of the rock from Liipola, described above. The same composition was also found in other specimens from this vicinity. A specimen of the rock from near Auranen showed quite different characters, although megascopically it can hardly be distinguished from the former rocks. It shows knots of quartz in a fine grey ground-mass the indivdual grains of which average about 0.3 mm in diameter. The rock is composed of quartz, microcline, biotite, muscovite, zoisite and plagioclase (?). The two first-mentioned minerals are present in nearly equal amounts, and the micas are also abundant. Zoisite, in large individuals, is an accessory. A few very small grains of a colourless mineral showing a refringence and birefringence like that of anorthitic plagioclases, but without twinning or cleavage are enclosed in quartz and microcline. This rock must be very potassic, and presents a sharp contrast to all examples hitherto considered, which are sodipotassic or dosodic.

The quartz-porphyritic rock near Lake Isojärvi.

A quartz-porphyritic rock occurs in close association with the largest batholith of oligoclase-granite, forming its contact-modification, round Lake Isojärvi northwest of Skogböle. The rock is composed of quartz and albite-oligoclase with some biotite and hornblende and is free from microcline. As to its structure it is most like the porphyritic rock from Valkjärvi near Skogböle. Large nodules of granulated quartz often 2 cm in diameter, as well as smaller individuals of plagioclase are to be found in a fine-grained ground-mass. This rock, which, in hand specimens, can not be distinguished from certain quartz-porphyritic rocks occurring within the leptite-belt, is here seen to grade into the oligoclase granite.

The relations between the blastoporhyritic leptites and the oligoclase-granites.

Some of the blastoporphyritic leptites are undisputably volcanic rocks. Such is the rock from Lapinkylä, in which the only effect of metamorphism has been the devitrification of the ground-mass, which certainly originally contained glass. Rocks of this type are frequently accompanied by tuffitic agglomerates. This is the case near the village of Liipola and on Hyyppiämäki (page 155). These rocks, primarily true liparites or dacites, are certainly older than the oligoclase-granite, as is clearly seen in the contact near Lapinkylä (page 134). An analysis of such a rock (p. 136) proved it to be different from the oligoclase-granites in so much as it contains less lime than any of the latter.

Other of the porphyritic leptites show a less pronounced supercrustal character in their structure and mode of occurrence, and intersect both the rocks adjacent to the oligoclase-granite and the granite itself after the manner of intrusive dikes. Such an intrusive contact as is found near Valkjärvi is a positive proof of the existence of blasto-porphyritic persalane rocks which are newer than the oligoclase-granite. Chemically they are of a more marked granodioritic character than the oligoclase-granites.

The third group of blastoporphyritic rocks comprises rocks which are undoubtedly immediately connected with the oligoclase-granites whose endogeneous contact-modifications they are. The rock from near lake Isojärvi just mentioned belongs to this group. Moreover, the contact-modifications of the Orijärvi batholith, described in detail above (page 53), are quite analogous with this Isojärvi rock, and their blastoporphyritic structure is no less pronounced. These rocks seem also to be chemically closely related to the oligoclase-granite.

The porphyritic rocks near Orijärvi also are, for the greatest part, chemically very similar to the oligoclase-granite, and it is not impossible that they are connected genetically with the neighbouring batholith. In the field there are no positive proofs for a volcanic origin of this particular rock belt, though the rock must certainly have been distinctly porphyritic originally. It may well be a sill and belong to the same class of intrusive bodies with those occurring in the Orijärvi basin, as described on page 61.

The even-grained leptites.

The leptite from Wetjo, Kisko.

These fine-crystalline quartz-feldspar rocks form the main part of the area which has been termed the leptite belt, and the interstratified layers of amphibolites and limestones are embedded in them. There is no general difference in their mode of occurrence in the different parts of the area. A marked bedded structure is characteristic of all, and the composition of the individual layers is exceedingly variable. We shall give details of a few examples.

A specimen of a dark grey hornblende-leptite from the village of Vetjo, in the district of Orijärvi, was subjected to a quantitative examination. The chemical analysis, made by the writer, led to the results quoted in table XXII.

Table XXII.

	%	Mol. prop.	Mol. %	Norm			Mode	
SiO_2	69.52	1.159	75.0		Q	30.60 %	Quartz	34.1 %
Al_2O_3	13.58	.133	8.6		Or	8.90	Microcline	7.3
Fe_2O_3	0.51	.003			Ab	29.87	Albite	26.4
FeO	3.75	.052	4.0		An	16.68	Anorthite	8.6
MnO	0.19	.003			Σ sal	86.05	Hornblende	20.1
MgO	1.22	.030	1.9	Di	$CaSiO_3$	1.97	Epidote	1.7
CaO	4.53	.080	5.2	Di	$MgSiO_3$	0.70	Biotite	0.7
Na_2O	3.55	.057	3.7	Di	$FeSiO_3$	1.32	Titanite	0.8
K_2O	1.47	.016	1.0	Hy	$MgSiO_3$	2.30	Apatite	0.3
TiO_2	0.64	.008	0.5	Hy	$FeSiO_3$	4.49		100.0
P_2O_5	0.20	.001	—		Mt	0.70		
H_2O	0.71	—	—		Il	1.22		
					Ap	0.34		
					Σ fem	13.04		
	99.87		100.0			99.09		

Tonalose.

Osann's system:	s	A	C	F	n	a	c	f	k
	75.6	4.7	3.9	7.2	7.9	6	5	9	2.28

The amounts of titanite, biotite and epidote were determined by the Rosiwal method, and that of apatite was calculated from the percentage of phosphoric pentoxide. All the magnesia and ferrous oxide remaining after the subtraction of the compounds of the above minerals must enter into the hornblende, as no further mafic minerals are present. CaO, Na_2O, K_2O an TiO_2 were allotted to (Mg,Fe)O in the proportions of the analysis of hornblende from the syenite of Biella, Piedmont, Italy[1]; the remaining oxides were calculated as feldspars and quartz, and the alumina not needed for feldspars was assumed to be present in the hornblende.

The plagioclase has, according to the calculation, the composition $Ab_{76}An_{24}$. This result does not quite agree with the re-

[1] »Quant. Classific.», table XIII, h.

sults of the microscopical examination. It could be determined exactly that $\omega > \beta$, and accordingly that the plagioclase must contain more than 78 % Ab. Sections $\perp$ $\mathfrak{c}$ show extinction angles from 0° to 3°, corresponding to some mixture between $Ab_{90}An_{10}$ and $Ab_{80}An_{20}$. Probably the hornblende of this rock does not contain so much soda (2.46 %) as assumed.

Twinning is almost entirely absent in the plagioclase, while microcline is frequently twinned, often only according to the albite-law. In this case the microcline might well be mistaken for plagioclase if its lower refringence were not looked for.

According to the calculation should the hornblende contain 5.5 % MgO, 18.1 % FeO and 17.5 % Al_2O_3. It has very dark colours: $\mathfrak{a}$ = brownish green $<$ $\mathfrak{b}$ = dark olive green = $\mathfrak{c}$ = dark green, not bluish. $c : \mathfrak{c} = 18°—19°$.

$$\beta_{Na} = 1.678 \pm 0.002.$$

The dark colours are probably owing to the high percentage of alumina, while the high refringence may be attributed to the predominance of iron over magnesia.

The structure of this rock is that of a hornfels. The felsic minerals show only polyhedral sections of an average diameter of 0.01 mm. The hornblende has an idioblastic development and its prisms are from about 0.03 × 0.07 to 0.06 × 0.3 mm in size. Epidote and titanite form globular aggregates of minute grains.

In this fine-grained mass there are scattered larger crystals of quartz, often granulated, as is usual in leptites. Furthermore there are fragment-like sharply bounded inclusions of various composition, either paler or darker than the ground-mass (pl. III, fig. 3). Occasionally such fragment-like inclusions are visible to the naked eye.

Such a fragmental structure and the absence of any features indicative of an igneous origin makes it probable that the rock had been originally a clastic sediment.

On the other hand, the bulk composition of this rock is quite typical of an igneous rock, and we may therefore assume that it was formed from volcanic ashes and tuffs. The chemical composition makes it probable that weathering had not been active, for alumina is deficient and soda is present in excess of potash and the lime bears a proportion to the other oxides which is usual in granodioritic eruptives.

The specimen was taken from a layer some 10 m thick which is quite homogeneous. The alternating layers in this tract are all dark-coloured and rich in either hornblende or biotite.

As another example of aphanitic leptites we take one which occurs 1 km south of Aijala, Kisko. A laminated structure, by the alternation of darker and lighter bands of a few millimeters in thickness is clearly marked. Under the microscope the lighter laminae were seen to be rich in muscovite, while the darker contain biotite. A chemical analysis was made for me by Mr. O. Stenberg (table XXIII). *The leptite south of Aijala, Kisko.*

Table XXIII.

	%	Mol. prop.	Mol. %	Norm		Mode	
SiO_2	78.40	1.307	84.6	Q	48.78 %	Quartz	50.0 %
Al_2O_3	12.13	.119	7.7	Or	26.69	Microcline	16.1
Fe_2O_3	0.66	.004		Ab	14.15	Albite	14.1
FeO	0.76	.011	1.2	An	3.06	Anorthite	3.1
MnO	0.03	—		Cor	3.26	Sericite	10.9
MgO	0.43	.011	0.7	Σ sal	95.94	Biotite	5.7
CaO	0.64	.011	0.7	Hy $MgSiO_3$	1.10		99.9
Na_2O	1.68	.027	1.8	Hy $FeSiO_3$	1.19		
K_2O	4.52	.048	3.1	Mt	0.93		
TiO_2	0.17	.003	0.2	Il	0.30		
H_2O+	0.61	—	—	Σ fem	3.52		
H_2O-	0.13	—	—		99.46		
	100.18		100.0				

M i h a l o s e near T e h a m o s e.

Osann's system:	s	A	C	F	n	a	c	f	T	k
	84.8	4.9	0.7	1.9	3.7	13	2	5	2.1	2.59

In calculating the mode all the FeO, MnO, MgO and Fe_2O_3 were assumed to be present in the biotite which is the only mafic mineral of this rock, and all the Na_2O and CaO to enter into the composition of the plagioclase.

The amounts of microcline and sericite were calculated from the remainder left after the subtraction of the above compounds, and the final residue of SiO_2 was considered as quartz.

According to the calculation from the analysis, the p l a g i o c l a s e has the composition $Ab_{83}An_{17}$. From its optical properties it should be somewhat more albitic, for all the grains have lower indices of refraction than the quartz, and the maximum extinction angle in symmetrical sections is 12°, indicating the composition $Ab_{88}An_{12}$. Some quantity of lime is probably segregated in the alteration products of the larger grains of plagioclase which are turbid from nondeterminable dusty substance.

This rock consists of a fine-grained mass, the individual grains averaging 0.05 mm in diameter. In this hornfels there are scattered larger individuals and groups of quartz and plagioclase which are discernible to the naked eye, often measuring 0.5 mm in diameter.

The larger individual grains of quartz are remarkably often idiomorphic showing the bipyramidal shape characteristic of quartz phenocrysts of volcanic rocks (pl. III, fig. 4). The appearance of these crystals has a close resemblance of those which H. Bäckström described from »hälleflintgneis» (leptite) in the Westanå region [1] and explained as original phenocrysts (cf. pl. 4, fig. 17 in the treatise of Bäckström).

The larger individuals and groups of plagioclase probably also represent original phenocrysts (pl. III, fig. 4). Either they have retained their original individuality and are in that case turbid, or they have been granulated to a hornfels of water-clear individual grains of polygonal shapes (cf. pl. III, fig. 2).

It is remarkable that only plagioclase occurs as phenocrysts, though the rock is rich in potash. The same relation was found in the blastoporphyritic leptite from Lapinkylä (p. 133) with which the present rock is possibly related genetically.

The composition of the rock in question is usual for igneous rocks. In Washington's tables 9 analyses of mihaloses, all volcanic rocks (rhyolites and liparites) are given, and many examples of the Tehamose subrang are also throughout similar to the analysis of the leptite from Aijala.

Both the composition and the structure indicating a volcanic origin, it is of minor importance whether the rock had originated as a lava-bed or as tuffite. The bedded structure tends towards the latter alternative, whilst the presence of phenocrysts and the occurrence as a homogeneous mass make the former assumption more plausible.

The leptite from Liipola, Kisko.

A specimen of a red leptite from the village of Liipola was analyzed by Mr. O. Stenberg (table XXIV).

The mode was calculated on the assumption that the lepidomelane has the composition of the lepidomelane from the granite of

[1] H. Bäckström, «Vestanåfältet». *Sv. Vet.-Ak. Handl.*, **29**, N:o 4, p. 54, 1897.

Table XXIV.

	%	Mol. prop.	Mol. %	Norm		Mode	
SiO_2	78.02	1.300	83.7	Q	39.60 %	Quartz	40.0 %
Al_2O_3	12.22	.120	7.7	Or	18.90	Microcline	17.8
Fe_2O_3	0.61	.004		Ab	36.15	Plagioclase	38.1
FeO	0.86	.012	1.4	An	1.95	Lepidomelane	2.2
MnO	0.01	—		Cor	1.02	Magnetite	0.6
MgO	trace	—	—	Σ sal	97.62	Titanite	0.1
CaO	0.41	.007	0.5	Hy	1.06		98.8
Na_2O	4.28	.069	4.4	Mt	0.93	Al_2O_3	1.0
K_2O	3.16	.034	2.2	Il	0.15	H_2O	0.4
TiO_2	0.11	.001	0.1	Σ fem	2.14		100.2
H_2O+	0.35	—	—		99.76		
H_2O-	0.13	—	—				
	100.16		100.0				

Subrang 4, dosodic, of Alaskase.

Osann's system:	s	A	C	F	n	a	c	f	T	k
	83.8	6.6	0.5	1.4	6.7	15.5	1	3.5	0.6	

Cape Ann. Mass. [1] This mineral forms lenticular groups of some 1.2 mm in length and appears also as scattered minute scales. There are also small amounts of a colourless mica associated with the lepidomelane and showing the characteristics of sericite.

Magnetite also is found in these groups as minute irregular grains. A small quantity of titanite is present, forming aggregates of minute globules.

Only 1.02 % Al_2O_3 remains after the calculation. This is partly due to the sericite which was not considered.

The main part of the rock consists of a hornfels of microcline, plagioclase and quartz. The average grain is about 0.05 mm in diameter but each mineral occurs also as larger individuals or groups, up to 0.6 mm in diameter. These do not show any idiomorphism or other features suggestive of original phenocrysts.

The plagioclase has, according to the analysis, the composition $Ab_{96}An_4$ which is in accordance with its low refringence and a maximum extinction angle of 18° in sections ⊥ (010).

[1] »Quant. Classific.», table XIV, e.

There is nothing in the structure of this leptite to give any hint as to its origin. It may have been an aphanitic rhyolite as well as a fine pelite. The chemical composition, on the other hand, agrees with that of many volcanic and hypabyssal rocks.

The specimen was taken from a homogeneous layer some 15 m in thickness which is bounded by narrower alternating layers of various composition: some are red-coloured and poor in mafic minerals and other layers are dark grey and contain much biotite and hornblende. Hence the geological mode of occurrence seems to be most in favour of the supposition that the rock in question was originally a sediment, though probably formed from volcanic materials.

The mineral composition of the leptites.

The above examples may give an idea of the composition of the most common types of leptites in the Orijärvi region. The microscopical study of these rocks proved that the range of variation is much wider. In many examples no plagioclase is to be found. More often microcline is absent. The plagioclase varies from albite to bytownite-anorthite, and the most calcic plagioclases were found in leptites which are rich in quartz and contain only small amounts of biotite as a mafic constituent (Such anorthite-leptites occur e. g. north of the great amphibolite sill near Orijärvi). Hornblende is usually present, and where it becomes abundant, the rocks assume an amphibolitic character and often grade into true amphibolites, devoid of quartz.

The following associations of minerals always accompanied by quartz have been observed in the leptites:

Microcline, biotite, muscovite, plagioclase.
Microcline, biotite, muscovite.
Plagioclase, microcline, biotite.
Plagioclase, microcline, biotite, hornblende.
Plagioclase, biotite, hornblende.
Plagioclase, biotite.
Plagioclase, biotite, muscovite.

It is a noteworthy fact that muscovite never was found associated with hornblende.

In the vicinity of limestone leptites often contain diopside. No biotite was found in such varieties, but hornblende is always present (cf. p. 59).

It would be almost impossible to separate the varieties of different composition on maps, owing to the irregular variability of the layers. Fig. 24 illustrates the bedding as frequently developed. The thickness of the individual layers is quite variable and no regular alternation has been detected. Certain layers are almost free from dark minerals, whilst others are rich in biotite or hornblende. In numerous exposures the bedding is scarcely perceptible in the field, but a microscopic examination may reveal an alternation of laminae which are rich in microcline and such without any potash feldspar.

The microscopic study of the leptites seems to indicate that the types rich in plagioclase are more abundant than the potassic varieties. The former more especially build up thick and homogeneous layers. Markedly bedded or laminated leptitic rocks usually have certain beds rich in microcline. In the same way narrow layers intercalated with limestones are often almost devoid of plagioclase.

Fig. 24. Bedded leptite. Near Kullajärvi, south of Skogböle, Tenala.

The leptitic gneiss.

The leptite in the vicinity of the granite-masses generally grades into gneissic rocks which differ from the usual leptites only in their texture which is more coarsely crystalline, the grain varying from 0.1 to 1 mm in diameter. These rocks have a very well developed pavement structure, often of a remarkable regularity (the »honeycomb» type).

No difference can be detected between those leptitic gneisses which adjoin the boundaries of the microcline-granites and those which form aureoles round the oligoclase-granites except that the former are usually injected with granitic or pegmatitic veins. The frequent alternation of layers and laminae of various composition is observable in both cases just as in the ordinary leptites.

In the western part of the parish of Perniö all the leptite rocks of the leptite belt have been altered into gneisses. Here also sodic and more potassic types alternate. Most specimens hitherto examined proved to be plagioclase-gneisses, with little or no microcline. Biotite is generally abundant, and the percentage of potash in the rock must therefore be rather considerable. Thus a specimen from Hirvlahti, Perniö, was found to contain 47.1 % quartz, 43.8 % plagioclase ($Ab_{65}An_{35}$), 7.5 % biotite, 1.1 % chlorite and sericite, 0.3 % magnetite and 0.2 % calcite. Another specimen, from Träskböle, gave 43.8 % quartz, 27.0 % plagioclase ($Ab_{63}An_{37}$) and 29.2 % biotite.

Cordierite-leptite and phyllite.

The cordierite-leptie. The cordierite-leptite occupies two areas, one north and another east of the church of Kisko (map I).

This rock is grey in colour and markedly schistose owing to the parallel arrangement of the abundant scales of biotite. A bedding is generally visible and many kinds of leptite rocks are intercalated as thin layers. On the whole, however, the areas of cordierite-leptite are remarkably uniform both in composition and structure (fig. 25).

The most characteristic feature of this wock is the occurrence of rounded nodules, from 0.5 to 1.5 cm in length, which differ from the ground-mass in so far as they do not contain visible scales of mica. These nodules consist of cordierite or are pseudomorphs after that mineral.

Under the microscope the rock was invariably found to have a fine- grained hornfels mass with pavement structure. The grain averages about 0.08 mm. This mass is composed of plagioclase (oligoclase or andesine), quartz and biotite and smaller amounts of ilmenite, apatite and zircon. Almandine is occasional. Often the biotite is greatly altered to chlorite which then encloses frequent needles of rutile.

The order of relative abundance of the three chief constituents is often the same in which the minerals were mentioned above, but in places biotite is prevalent over each of the felsic minerals.

The nodules are rather various in their actual habit. Most common are such composed of a pale-brown aggregate of extremely small scales. These, when large enough to be discerned, are seen to be strongly birefractive and pleochroic. In this mass there are minute inclusious of zircon (?) which are surrounded by orange-coloured halos. These properties make it probable that the mineral which composes the patches is allied to biotite. It cannot be ascertained whether there is also sericite present or not.

In another specimen the outer parts of the nodules consist of green chlorite and the inner parts still contain cordierite. In other cases remnants of cordierite are present throughout the nodules and have retained their individuality, but are in process to be altered into the micaceous mass.

Many of the intercalated layers in the cordierite-leptite contain anthopyllite, developed as prisms much larger in size than any other constituents of this rock. In a specimen from Liisanmäki

Fig. 25. Cordierite-leptite with an intercalated lenticle of anthophyllite-bearing cordierite-plagioclase-rock. $^1/_4$ nat. size. Near Toivola, north of the church of Kisko.

north of the church there was found, under the microscope: plagioclase in excess of quartz, forming a fine-grained hornfels, and prisms of anthophyllite, up to 1 cm in length, arranged in radiating bunches. Dark brown biotite is present in an amount equal to that of the anthophyllite. Chlorite, ilmenite and apatite are minor constituents. The nodules of cordierite which are scattered in the hornfels mass are also traversed by the prisms of anthophyllite.

The anthophyllite shows properties similar to those of the varieties of this mieral described in another part of this treatise. Thus the mineral is optically positive with a large axial angle and has the usual orientiation: a = 𝔞, b = 𝔟, c = 𝔠, and the pleochroism: 𝔞 = pale brown < 𝔟 = greyish brown < 𝔠 = bluish grey.

The cordierite leptites have not yet been subjected to any quantitative analysis, but it is evident from their mineralogical composition that they must have a bulk composition characteristic of clayey sediments, with excessive alumina, high percentage of potash and low of lime. Petrographically these rocks are analogous to the hornfels of class 3 of V. M. Goldschmidt [1], or plagioclase-cordierite-hornfels. The anthophyllite-bearing varieties, on the other hand, agree with Goldschmidt's class 4 or hypersthene-plagioclase-cordierite-hornfels, amphibole being present in this area instead of the heteromorphous pyroxene.

Rocks of a similar mineralogical composition to those just described, are also found within the contact-zone round the Orijärvi-granite and will be described later.

The phyllite near Hyyppiämäki, Kisko.

West of the village of Haapaniemi in the parish of Kisko, about a hundred meters South of the Hill named Hyyppiämäki, there is an

Table XXV.

	%	Mol. prop.	Mol. %	Norm	
SiO_2	72.99	1.216	78.4	Q	49.08 %
Al_2O_3	10.32	.101	6.5	Or	11.68
Fe_2O_3	0.73	.004		Ab	4.72
FeO	7.03	.101	7.0	An	10.56
MnO	0.06	.001		Cor	3.37
MgO	1.99	.050	3.2	Σ sal	79.41
CaO	2.15	.038	2.5	Hy $MgSiO_3$	5.00
Na_2O	0.57	.009	0.6	Hy $FeSiO_3$	12.01
K_2O	2.02	.021	1.4	Mt	0.93
TiO_2	0.47	.006	0.4	Il	0.91
C	0.07	—	—		18.85
H_2O+	1.09	—	—		98.26
H_2O-	0.32	—	—		
	99.81		100.0		

Osann's system:	s	A	C	F	n	a	c	f	T	k
	78.8	2.0	2.5	10.2	3.0	2.5	3.5	14	2.0	2.29

[1]) »Die Kontaktmetamorphose im Kristianiagebietet.» p. 156.

abrupt rock-wall which shows a section across a series of leptites. This series includes a layer of a dark grey and schistose rock which is exposed in the southern end of the wall. The visible part of this layer is only two meters thick. An analysis of this rock, made by Mr. O. Stenberg, is given in table XXV.

The mode can not be given in this case because I have not been able to determine all the constituents under the microscope. The largest grains of quartz are 0.03 mm in diameter and the average grain is about 0.005 mm. The following coloured minerals have been distinguished: Brown biotite, bluish steel-coloured iron ore (ilmenite?) and dull opaque particles which a chemical test proved to consist of carbon. The transparent minerals, of which quartz is most abundant, form a hornfels mass. The minute scales of biotite are parallel and give the rock a marked schistose habit.

It is at once apparent from the analysis that this rock is not of igneous origin. The ratio $F:Q = 49.1 : 27.0 > 5 : 3$ ranges it with an order of the quantitative classification which has no representatives in Washington's tables. The percentages of the metallic atoms calculated according to the proposition of Becke [1], are as follows:

Si	72.7 %
U	21.5 »
L	5.8 »

If these figures are plotted on the triangular projection, the rock takes its place in the midst of the field of sedimentary rocks. It does not, however, belong to the ordinary argillaceous sediments, having a low percentage of alumina, but is related to ferrugineous shales.

The agglomeratic rocks.

Fig. 26 shows the typical appearance of a rock which is very common in the leptite belt of southwestern Finland, being characterized by lighter leptitic framents in a darker amphibolitic mass. The

[1] F. Becke, »Chemische Analysen von krystallinen Gesteinen aus der Zentralkette der Ostalpen», Denkschr. Ak. Wiss. Wien, Mat.-Naturw. Kl. LXXV, p. 194.

invariable habit of this type is in fact remarkable. Many features in its structure and mode of occurrence make it probable that they were originally volcanic agglomerates, as might appear from the following description of a few examples.

Fig. 26. Agglomeratic rock, containing leptitic fragments in an amphibolitic mass. 1/4 nat. size. Saari, Perniö.

The agglomerate near Skogböle, Tenala.

Such fragmental rocks occur as a large mass near the Valkjärvi farm north of the station of Skogböle, Tenala (see map I). This area was explored in great detail by Dr. B. Frosterus who was the first to explain the rocks under consideration as volcanic products.

A specimen containing only small fragments (about 1 cm in length) was analyzed by the writer (table XXVI).

In the slices made from that specimen which was used for the analysis, all the fragments consisted of a fine hornfels of quartz, microcline and plagioclase and green hornblende. The grain varies from 0.01 to 0.06 mm in diameter. In this mass are embedded nodules of the size and form of small peas, which are composed of epidote, zoisite and calcite.

Table XXVI.

	%	Mol. prop.	Mol. %	Norm	
SiO_2	61.70	1.028	99.9	Q	14.52 %
Al_2O_3	13.83	.135	8.8	Or	14.46
Fe_2O_3	1.26	.008		Ab	28.82
FeO	5.59	.078	6.2	An	15.01
MnO	0.15	.002		Σ sal	72.81
MgO	2.18	.056	3.7	Di $CaSiO_3$	8.70
CaO	7.36	.132	8.6	Di $MgSiO_8$	3.60
BaO	0.04	—	—	Di $FeSiO_3$	5.15
Na_2O	3.37	.055	3.5	Hy $MgSiO_3$	2.00
K_2O	2.42	.026	1.7	Hy $FeSiO_3$	2.90
TiO_2	0.72	.009	0.6	Mt	1.86
P_2O_5	trace	—	—	Il	1.37
CO_2	0.23	.003	—	Σ fem	25.58
H_2O+	0.52	—	—		98.39
H_2O-	0.16	—	—		
	99.53		100.0		

Osann's system:	s	A	C	F	n	a	c	f	k
	67.5	5.2	3.6	14.9	6.7	4.5	3.0	12.5	1.27

The matrix contains hornblende, plagioclase (andesine), quartz, microcline, epidote and zoisite, titanite and diopside. The grain is coarser than in the fragments, and the schistosity is pronounced.

No other analysis given in the present paper shows so high a proportion of femic lime as this. The ratio (Mg,Fe)O : CaO″ = 1.74 is almost the same as the minimum value of this ratio in the hornblendes which is 1.73. It might therefore be supposed that all the femic lime does not enter into the hornblende, but that diopside must be present (cf. p. 128). This is in fact the case.

Such a high proportion of lime is unusual in normal igneous rocks. Its presence here can be explained as being due to secondary processes. The small nodules of epidote and calcite may be interpreted as amygdules, and the lime silicates as formed during metamorphism by interreaction of the ferro-magnesium silicates and calcite (cf. p. 108). Thus the bulk composition of this rock agrees with the hypothesis that it is of pyroclastic origin.

One of the fragments examined microscopically had a porphyritic structure with phenocrysts of plagioclase and quartz. Other fragments are pale green in colour and are composed of epidote minerals with plagioclase, microcline and quartz. These fragments are usually larger than the leptitic fragments. Moreover, there are fragments of limestone which, in the rock-surface, have been etched out by solution.

The agglomerates near Kulju, Kisko. A series of agglomeratic rocks is exposed on the southwest shore of Lake Liipolanjärvi, near the cottage of Kulju (fig. 27).

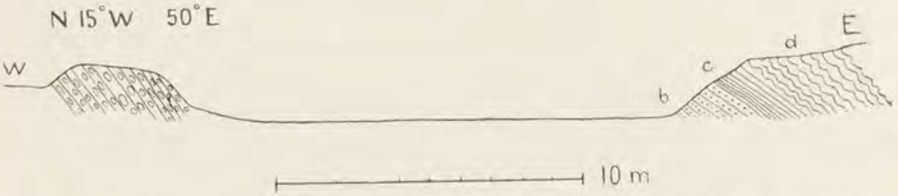

Fig 27. Section across a series of agglomeratic rocks. Kulju, Liipola, Kisko.

Layer (a) consists of a common type of agglomerate (fig. 28), in which lenticular or irregular fragments of leptite are enclosed in a dark-coloured matrix. The leptitic fragments are composed of plagioclase, quartz and hornblende and some of them have indistinct porphyritic structure. The matrix consists chiefly of hornblende and small amounts of iron ores.

Layer (b) is formed of dark schistose leptite. The mineral constituents are quartz, plagioclase ($Ab_{62}An_{38}$), biotite, microcline and hornblende. Occasional rounded fragments of porphyritic amphibolites and such of a green-coloured epidositic rock are enclosed in the leptite. This layer may have been originally a tuffitic bed of fine materials in which volcanic bombs of basaltic composition were embedded.

Layer (c) is composed of alternating light and dark laminae of leptite and amphibolite, and is overlaid by layer (d) which is composed of a blastoporphyritic rock showing, on well exposed surfaces, a characteristic structure of the »pillow-lava». This rock contains phenocrysts of plagioclase embedded in a hornfels mass of plagioclase, amphibole and iron ore. The phenocrysts often display a distinct primary zonal structure. The extinction angles in sections $\perp$ (010) and (001) vary from $+ 14°$ to $+ 24°$ (68 to 55 % Ab). The amphibole is partly green common hornblende, partly colourless with a higher birefringence. Both occur in a manner similar to the cummingtonite and hornblende in the Orijärvi amphibolite (p. 112). The amphiboles are subordinate and the bulk composition of this rock must be that of an andesite. If the colourless amphibole is cummingtonite, the rock must have originally contained hypersthene.

It seems evident that we have here a series of volcanic rocks and that the agglomerate with leptitic fragments also belongs to that series.

Fig. 28. Agglomerate from Kulju, Liipola, Kisko.

The agglomerates at Hyyppiämäki, Kisko.

At the southern boundary of the belt of amphibolites west of the village of Haapaniemi in Kisko, both leptites and amphibolites are associated with agglomeratic rocks. A very instructive exposure is that on the southern slope of a hill named Hyyppiämäki. Furthest to the South one finds a small exposure of blastoporphyritic leptite with phenocrysts of quartz and plagioclase. North of this there is a leptitic agglomerate, composed of irregular sharp-edged and rounded fragments of blastoporphyritic pale grey leptite and such of a dark grey aphanitic leptitic rock, similar to certain types found as layers further south. The size of the fragments varies; some as much as 8 cm in diameter were observed. The matrix consists of smaller fragments of leptitic rocks and of small milk-blue crystals of quartz which often show a bipyramidal crystalline form, or rounded shapes

Fig. 29. Agglomeratic rock south of Hyyppiämäki, Kisko. $^1/_7$ nat. size.

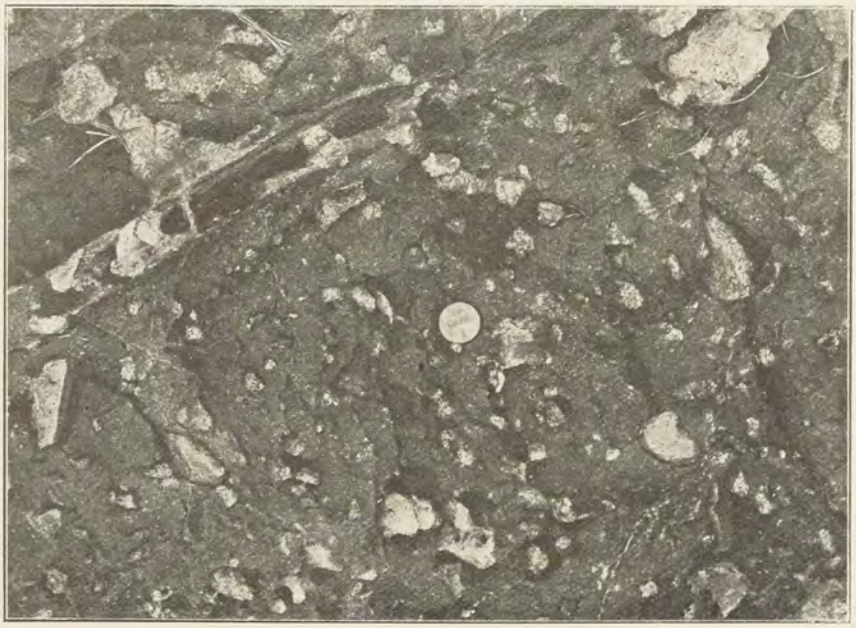

Fig. 30. Agglomeratic rock near Kolkko, shore of Lake Määrijärvi, Kisko. $^1/_5$ nat. zize.

with traces of magmatic corrosion. Even the finest portion is distinctly clastic when seen in unpolarized light under the microscope. On the whole, this rock in all its features is very like many nonmetamorphic liparitic agglomerates.

This leptitic rock grades to the North into an amphibolitic agglomerate, the matrix becoming gradually dark from hornblende. Amphibolite also appears as fragments and the rock passes into a blastoporphyritic amphibolite showing agglomeratic structure. When this structure has disappeared, the porphyritic habit remains visible. Finally this also disappears and the rock is now an even-grained, perfectly granoblastic amphibolite without any traces of its original structure. Along the southern boundary of this same belt agglomeratic rocks are exposed at several other localities (map II).

Fig. 29 shows the appearance of the agglomeratic rock which occurs along the northern boundary of the amphibolite mass south of Hyyppiämäki. The fragments are leptitic, but various in colour and composition. The matrix contains porphyritic individuals of plagioclase.

West of the Orijärvi granite mass, along the shores of Lake Määrijärvi there are numerous occurrences of agglomeratic rocks. The fragments embedded in an amphibolitic mass are either of leptite or of amphibolite. Many of them are amygdaloidal, as in the example illustrated by fig. 30. On the rock-surface the calcite of the amygdules has been removed by weathering and the appearance of the rock is then very like that of a recent pumice.

The origin of the leptite-rocks.

The bedded or laminated structure so generally present in the leptites can hardly be accounted for unless it is assumed to have originated as original bedding or stratification of the material. Some of the layers are like volcanic rocks, other have the composition of aluminous sediments and still other intercalated layers are of limestones. This must be attributed to the alternation of various volcanic and sedimentary materials in the deposition of the leptite series.

It is remarkable that the sedimentary rocks in the area in question are represented only by argillaceous rocks and limestones. No quartzites have been met with, nor have I found any example of true conglomerates.

The limestone.

The crystalline limestones occur as layers intercalated with leptites and amphibolites. Thus they are conformable with the adjacent strata and are generally almost vertical. The thickness of the layers varies from a few centimeters to some fifty meters, and single beds can often be traced over several kilometers. A pinched out lenticular layer frequently reappears further along its strike. The distribution of the limestones may be seen from the maps.

The composition of the limestones.

The limestones of southwestern Finland so far as analyzed chemically are generally composed of very pure calcium carbonate. This will appear from the examples quoted in table XXVII.

Table XXVII.

	I	II	III	IV	V
Insoluble	2.79	0.27	5.78	7.10	13.78
SiO_2	—	—	—	—	0.06
$Al_2O_3+Fe_2O_3$	0.20	0.67	0.32	0.07	0.23
CaO	52.48	54.99	52.17	52.40	47.93
MgO	1.68	none	0.53	0.33	0.52
CO_2	42.76	43.83	39.47	39.81	37.67
H_2O	—	—	1.48	0.61	—
	99.91	99.76	99.75	100.32	100.19

I. Fine-grained limestone (»marble»), Limbergsgrufvan, Pargas. Analyst A. W. Forsberg. B. Frosterus, **35**, p. 9.

II. Red coarsely crystalline limestone, Sjöholm, Westlaks, Kimito, Analyzed by students at the chemical laboratory of the University of Helsingfors.

III. Limestone, Nicksor, Finnby. Analyst M. Dittrich. P. P. Sustschinsky, **41**, p. 104.

IV. Fine-grained limestone, Lammala, Westanfjärd. Analyst M. Dittrich. P. P. Sustschinsky, **41**, p. 66.

V. Limestone, Tytyri, Lohja. Analyst N. M. Slawsky. P. P. Sustschinsky, **41** p. 4.

Only in the western part of the leptite belt there are dolomites associated with the limestone. The dolomiteh as sharp boundaries towards the limestone and occurs as lenticular or sill-shaped masses. Sustschinsky has given an analysis of such a dolomite from the quarry of Lammala Östergård, Westanfjärd (**41**, p. 67).

Most of the analyses of crystalline limestone are usually made from comparatively pure material and therefore probably do not represent the true bulk composition of the layers which may contain more siliceous compounds than is shown as »insoluble» in the analyses. The purest limestones of the leptite belt are found in Kimito and Finnby and are there quarried and employed for burning lime. More usually, and especially in the parish of Kisko, the limestones contain very considerable quantities of siliceous minerals. Often the limestone occurs as thin laminae which are intercalated with equally thin laminae of leptites or amphibolites (cf. fig. 2, p. 13).

In other cases there are no continuous beds of silicate rocks, but a bedding may be no less evident owing to a special abundance of the siliceous minerals along certain lines or bands. It seems probable that these impurities in the limestone are generally of primary origin.

The most common accessories in the limestones are: quartz, microcline, plagioclase, various amphiboles, diopside and epidote (or zoisite or clinozoisite). In those limestones which are in immediate contact with granites there are numerous other minerals as normal constituents (not at the contacts only). Such are: wollastonite, chondrodite, phlogopite, titanite, grossularite, scapolite and vesuvianite.

As some of these minerals contain chemical elements which are alien to sedimentary limestones, an addition of such elements must have taken place. The bulk of the siliceous compounds, however, had presumably been present in the original sediment, and the crystallization of the »contact minerals» may be attributed to a normal contactmetamorphism.

The relations between the wollastonite and quartz deserve special attention. I have not found wollastonite in the limestones in the Orijärvi field, but quartz is usually present. In the limestone near Kärkelä, Karjalohja, wollastonite is a constituent of the limestone, but in a part of the exposure the limestone is free from wollastonite and contains abundant minute grains of quartz. This variety is fine-grained, while the wollastonite-bearing limestone is coarsely crystalline. This

Kärkelä limestone is situated in the midst of a migmatite area, and granite is immediately adjacent to that part in which the wollastonite is found.

Wollastonite also occurs in the limestone at the quarry of Lammala Östergård, Westanfjärd (cf. P. P. Sustschinsky, **41**, p. 74). A few hundred meters to the West from this occurrence there is another quarry and here the limestone, in places, contains quartz. Analysis IV, given by Sustschinsky, had been made from such a quartz-bearing variety (the insoluble residue, totalling 7.10 % contains 6.11 % SiO_2, l. c.). A calculation from this analysis proves, moreover, that this limestone must contain soluble calcium silicate also, giving 4.52 % $CaSiO_3$ and 3.78 % free silica. As the presence of wollastonite was thus suspectible, I examined microscopically a specimen collected by me from the same place in 1910, and found in fact that both wollastonite and quartz are present, besides calcite. In my specimen the greatest part consisted of the siliceous minerals. A calculation from several analyses made at the chemical laboratory of the University gave as a result that the rock contains about 9.5 $CaCO_3$, 2.5 % $MgCO_3$, 38 % $CaSiO_3$ and 50 % free SiO_2.

V. M. Goldschmidt [1] has shown that the system quartz-calcite-wollastonite can be used as a geological thermometer. Where wollastonite is present, the temperature has during the metamorphism exceeded a certain limit which varies with the pressure At atmospherical pressure this limit should be about 500° C and at increasing pressure rise, at first rapidly but then more and more slowly, to about 950° at 15,000 atm.

As quartz + calcite is in the Archaean of southwestern Finland of a more common occurrence than the wollastonite, the conclusion might be drawn that the metamorphism had taken place at temperatures which only rarely had risen above the quartz-calcite curve.

It may be suggested that the quartz has been added to the limestone by hydro-thermal processes later than the strongest metamorphism. There is in fact some evidence that so had happened in the case mentioned above, i. e. at the quarry of Lammala. The wollastonite and quartz occur along the wall of an amphibolite sill and the limestone is here distinctly sheared. Only such a »mylonitic» variety is quartz-bearing. The fact that both quartz and wollastonite are here associated with calcite can be explained on the assumption that silica was begun to be carried in before the temperature had finally sunk below the field of stability of the wollas-

[1] »Die Gesetze der Gesteinsmetamorphose, mit Beispielen aus der Geologie des südlichen Norwegens». *Videnskapselk. Skr. I. Mat.-Naturw. Kl.*, *N:o* 22, 1912.

tonite, but the process of silicification has proceeded still at lower temperatures.

In most cases, however, the quartz must have been in contact with calcite during all the stages of the metamorphism. The evidence is especially convincing in the case of narrow intercalated layers of leptite which contain only quartz and feldspar, in contact with the calcite, and no special contact-minerals.

Goldschmidt states, moreover, that the temperature-curve of magnesia-bearing silicates must lie below the wollastonite-curve. This is in agreement with the mineralogical characters of the limestones under consideration which generally contain magnesium-bearing silicates, such as tremolite and diopside, but no wollastonite. This circumstance leaves a way open for explaining the general absence of magnesium carbonate which was found to be characteristic of the limestones in the Southwest of Finland.

The structure of the limestone.

Limestones intercalated with leptites and occurring at long distances from granites are generally fine-grained, i. e. decimillimeter- or millimeter-grained. Near the contact with granites they are coarsely crystalline (centimeter-grained). Thus the limestones of Finnby, Kaukasalo and Pedersjö, as also most of the limestones of the Kisko leptite area, are rather fine-grained, while those in immediate contact with the Orijärvi granite and especially those near the masses of microcline-granite are coarse. Such are the limestones which are being quarried at Lammala, Bredvik, Sjöholm and Illo in the southern part of the island of Kimito.

As stated by Sustschinsky, is the structure of the limestone generally non-sutured (nicht-verzahnt). In other words, these rocks have a structure characterized by the rectilinear boundaries between the individual grains and being substantially identical with the pavement structure of the metamorphic siliceous rocks.

The contacts between the limestones and the rocks of supercrustal origin.

At the contact between limestones and siliceous supercrustal rocks there are often minerals which have been formed by chemical reaction between the silicates and calcium carbonate.

Where narrow layers of leptites, composed merely of quartz and feldspars, are intercalated with the limestone, there are usually no special contact-minerals. In specimens of such laminated rocks from the Orijärvi region only c l i n o z o i s i t e appears except the main constituents. In specimens from Skogböle m e i o n i t e occurs at the contacts between limestones and leptites.

But where the leptites are rich in mafic minerals, diopside and hornblende are generally abundant along the contacts. Thin laminae of limestone are often entirely converted into diopside-

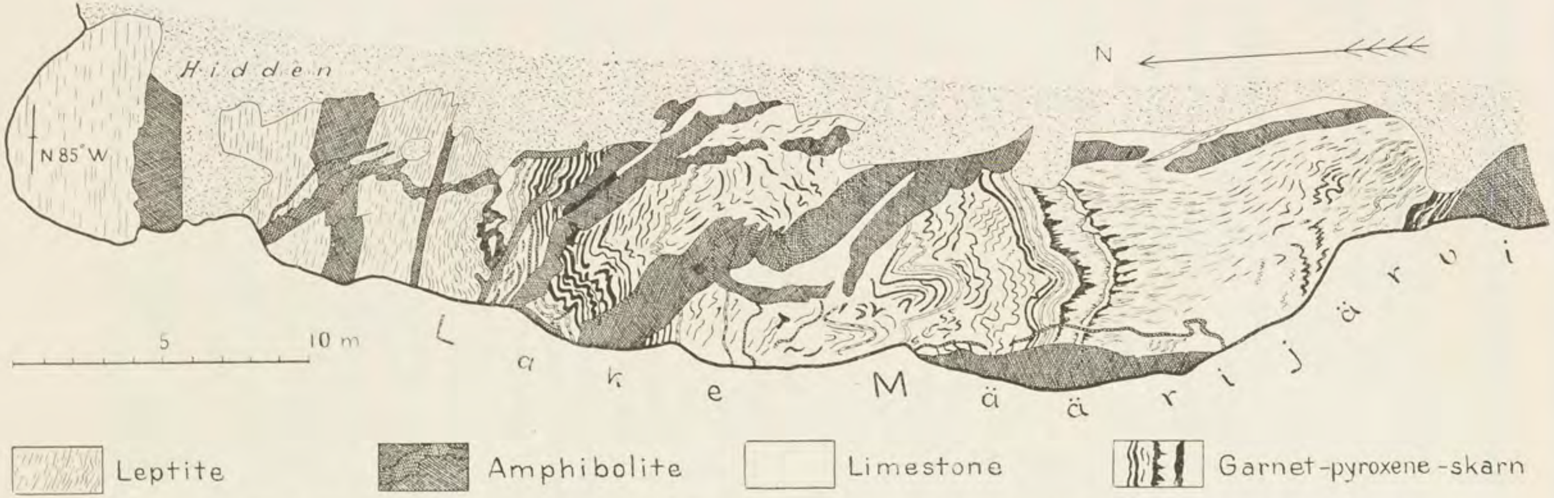

Fig. 31. Limestone intercalated with leptite and intersected by dikes of amphibolites. Western shore of the island of Aitsaari, Määrijärvi, Kisko.

amphibole-skarn. The narrow layers of skarn appear in the surface as lighter bands in the darker leptite. Such skarn-bearing leptites are common along a zone north of the Orijärvi mine, and are well exposed e. g. near the cottage of Mäkilä. These rocks form a continuous transition series between the leptites and the diopside-amphibolites, described above.

The amphibolites seen in contact with the limestone occur either as conformable layers intercalated with layers of limestone, or as sills or dikes. Fig. 2 (p. 13) illustrates the former kind of occurrence, and an example of the intersecting dikes is shown in fig. 31.

The conformable layers of amphibolites were probably originally beds of basaltic lava or tuff, and the intersecting dikes must also have been originally basaltic in structure, as they are in composition.

It is well known that basalts, even when they occur as dikes, exercise little or no contact-metamorphic influence on their country-rocks. [1] The post-Jotnian dikes of diabase (more correctly basalt) are, in their mode of occurrence, exceedingly similar to the dikes of amphibolite, except that these are disturbed by movements and metamorphosed. I had a thin section of the contact between limestone and a nonmetamorphic quartz-diabase from Ahvensaari, Korpo, the Åbo Archipelago, and could verify a perfect absence of any traces of new-formed contact-minerals.

Hence it might seem that the dikes of Archaean amphibolite had primarily caused no more changes in the invaded limestone. A study of the contact gives further evidence that the contact-minerals which are actually present along the contact-faces are of a secondary origin.

Dark-coloured skarn, composed of garnet and pyroxene, with small amount of epidote, is found at the boundaries of the limestone with the amphibolite as also with the leptite. Dark amphibolite bands and narrow veins are also surrounded by skarn, or they have been thoroughly converted into a mass of pyroxene and garnet. As seen in the sketch, the thin bands are generally associated with skarn, while the dikes, though much larger, are only surrounded by a thin shell of diopside. The smaller dikes and bands of amphibolite have frequently been broken up during the folding of the limestone (fig. 32). It is interesting to note that the broken ends of the fragments in such cases are coated by a mantle of skarn no thinner than that of the sides.

The d i o p s i d e is pale green in colour and forms large individuals which are intergrown with rounded grains of epidote or pla-

[1] Vide: H. Rosenbusch, »Mikr. Physiogr.» II, 2, p. 1294 (1908).

gioclase. The garnet is yellowish brown and does not show any crystalline form. The index of refraction, determined by the immersion method, is:

$$n_{Na} = 1.782.$$

As it can be concluded from the occurrence of this garnet that it belongs to grossularites or andradites, this refractive index proves that it is a mixture of both, but that the aluminous garnet forms the greater part.

Fig. 32. Dikes of amphibolite folded with the limestone and broken into pieces which are coated with garnet-pyroxene skarn. $1/_6$ nat. size. Aitsaari, Määrijärvi, Kisko.

In the Orijärvi region as well as elsewhere, andradite has been found to be alvays a pneumatolytic mineral, while the grossularite is also formed by normal contact-metamorphism which in the case of the Aitsaari rocks has certainly been the main agency, though an addition of ferric iron in a pneumatolytic way has probably also played a part. But the metamorphism cannot be attributed to the dikes or bands of amphibolite. The action must have been more of a regional kind and is in this case presumably due to the neighbouring oligoclase-granite.

Grossularite is found at numerous other localities at the contacts of the limestone with amphibolites or leptites, in the vicinity of the oligoclase-granites, both in the Orijärvi field and in the Skogböle tract.

The grossularite at the contacts of the limestones with supercrustal rocks is still more common in the vicinity of the microcline-granites. It is found e. g. in the quarries of Illo and Lammala [1] in the parish of Westanfjärd and near Kulla in Kimito.

V e s u v i a n i t e is associated with the grossularite in all the above-mentioned places and occurs in a similar manner at many other localities, e. g. on the islands of Pettu and Nicksor in Finnby, and near Ylikylä, Perniö. The writer has nothitherto observed anyi docrase in those limestones occurring in the contact-aureoles of the oligoclase-granites.

As appears from the foregoing statements, the genesis of the contact-minerals at the contact between the limestones and the metamorphic rocks of the supercrustal series was dependent on the influence of granitic masses. At a certain distance from the granites only diopside, hornblende and epidote occur. In the vicinity of oligoclase-granites grossularite is sometimes present, and in the neighbourhood of the microcline-granites vesuvianite is commonly associated with the garnet, and both are abundant.

The contacts between the limestone and the intersecting granite.

Pneumatolytic skarn rocks are common in the contact-zones of the oligoclase-granites. They are well developed in the Orijärvi field and will be described later, in connection with other rocks of the exogeneous contact-aureole round the Orijärvi granite. Here it may only be remarked that these products of the alteration of limestone, characterized especially by the occurrence of andradite, can easily be distinguished from the products of normal contact-metamorphism. The skarns also occur in the manner of true rocks and are tolerably homogeneous, which is not the case with the associations of minerals formed along the contacts by mutual interactions of solid constituents.

The contacts of the limestones with the microcline-granites or its pegmatitic modifications differ from those of limestone with the oligoclase-granites in many essential features. Pegmatitic dikes

[1] Sustschinsky describes the occurrence of garnet and vesuvianite at the contact between limestone and a dike of amphibolite near Lammala (**41**, p. 68—79). He regards the contact-wall, composed of grossularite, vesuvianite and diopside, as an original product of the contact-metamorphism caused by the amphibolite. The wollastonite which occurs along the opposite wall of the same dike is also explained in the same way. This hypothesis, however, can hardly be right (cf. above).

often show sharp contact with the limestone, without any contact-minerals. More often there was formed a contact-wall, composed of diopside, hornblende, meionite, grossularite, etc. The scapolite is especially characteristic and abundant. Such contact-walls are generally only a few centimeters thick and the limestone away from the junction is pure or contains only such minerals as products of normal contact metamorphism as were mentioned above (p. 159). Within the area under consideration pneumatolytic skarn was nowhere observed at the contacts of limestones with the microcline-granite.

This different behavior of the two groups of granites towards the limestone is probably a consequence of the different conditions under which they were solidified. The difference in the chemical composition of the magma was perhaps of little significance, but the composition of the magmatic gases may have played an important part.

The present writer has not yet studied the contact-phenomena of the microcline-granites in any detail. To Sustschinsky is due the credit for having given an exact description of these phenomena at numerous localities in southwestern Finland.

The exogeneous contact-zones of the oligoclase-granite.

Preliminary remarks.

Within a zone a few hundred meters broad — at its widest part 900 m — surrounding the batholith of oligoclase-granite near Orijärvi most rocks are, in structure and composition, different from the rocks of the leptite-area in general. They are especially characterized by the occurrence of cordierite and andalusite, i. e. two species which are commonly regarded as typical contact-minerals. Considering this fact in connection with the geographical distribution of these rocks round the granite batholith, which is intrusive in the surrounding schists, the explanation of the cordierite- and andalusite-bearing rocks as products of exogeneous contact-metamorphism seems quite natural. There is, however, a point deserving attention: Numbers of batholiths of oligoclase-granite occur in the leptite belt, petrographically and geologically closely resembling the Orijärvi granite, but excepting the latter, only one is partly surrounded by an aureole of similar contact-metamorphic rocks. Generally the leptites, in the immediate vicinity of the granites, are somewhat more coarsely crystalline and gneissose than elsewhere, but they do not contain contact-minerals. This fact, I think, will be better understood on a nearer acquaintance with the rocks from the Orijärvi area. A few preliminary remarks only are necessary here.

The leptites have mainly a composition characteristic of igneous rocks, and are chiefly composed of feldspars and quartz. A normal contact-metamorphism of such rocks, taking place without any change in the composition, may cause a recrystallization of the minerals, but thereby only quartz and feldspar can be formed, as there is no excessive alumina to give rise to andalusite or cordierite. Only where clayey sediments are influenced by contact metamorphism can such minerals be formed. Thus we may assume that, at the time of the intrusion of the oligoclase-granites, they became surrounded by aureoles of gneissose leptites, but the more remote parts of the leptite-masses remained feebly metamorphosed. Afterwards the whole supercrustal series was universally metamorphosed by the influence of the microcline-granite magma in which the former was immersed. The difference in the degree of the metamorphism was diminished thereby, and the clayey sediments in the area were converted into hornfels containing contact-minerals, such as the »cordierite-leptite» which occurs near the church of Kisko (page 148).

In the case of the contact-metamorphic aureole around the Orijärvi batholith two explanations seem possible: either, that the supercrustal mantle originally consisted of aluminous sediments, in which case the metamorphism would have taken place with unchanged bulk composition, or that the supercrustal mantle-rocks consisted of materials similar to the greater part of the leptite series, but the composition of the rocks was changed at the metamorphism owing to pneumatolytic agencies. One of our endeavours will be to find out which of these explanations may be applied.

In the Orijärvi area, the cordierite-bearing rocks are most common. These rocks show a great variability in composition and structure. As a rule, they are coarsely crystalline and nonhomogeneous, thus being little adapted for quantitative examination. The following combinations of minerals have been observed:

1. Chiefly cordierite and anthophyllite (+quartz and variable amounts of biotite):

Cordierite-anthophyllite-rock.

2. Cordierite, anthophyllite and plagioclase (+biotite and quartz): Cordierite-anthophyllite-gneiss.

3. Cordierite and quartz (+biotite): Quartz-cordierite-rock.

4. Cordierite and plagioclase (+biotite and quartz): Cordierite-gneiss.

Each of these mineral combinations occurs in the manner of true rocks and is sufficiently well characterized. The different types can be distinguished with the naked eye. Transitions between them are, however, so frequent and irregular that it is not possible to designate them on maps on such scales as those which accompany this treatise.

Round the northwestern point of the granite-area, andalusite-bearing rocks are widely spread throughout this part of the aureole. These rocks are still more nonhomogeneous in their composition and structure than the cordierite-bearing rocks, and especially the andalusite is very unevenly distributed. Nevertheless, it can be said that the andalusite-bearing rocks form a special type characterized by

5. Andalusite, quartz, sericite, biotite and also plagioclase:

Andalusite-bearing quartz-mica-rock.

Leptitic plagioclase-gneisses occur in close association with the cordierite- and anthophyllite-bearing rocks. Compared with the leptites they are rather coarsely crystalline, thus bearing evidence of a metamorphic influence which has not acted upon the leptites outside the aureole. This type is characterized by plagioclase, quartz and biotite:

6. Plagioclase-biotite-gneiss.

Further on, amphibolitic rocks are common, which are composed of plagioclase and cummingtonite. This rock we term

7. Cummingtonite-amphibolite.

In the aureole rocks are also met with whose composition and regular association with limestones proves them to be products of the alteration of limestones. They may be termed skarn, a name which has long ago been in common use in the Fenno-Scandian literature. The constituents are indicated through the prefixes:

8. Tremolite-skarn.
9. Hornblende-skarn.
10. Pyroxene-skarn.
11. Andradite-skarn.

Finally, there are two kinds of occurrences of ores within the aureole:

12. Oxide ores (magnetite), and
13. Sulphide ores (chalcopyrite, sphalerite, galenite, pyrrhotite etc.).

The cordierite-anthophyllite-rock of Träskböle in Perniö.

The most peculiar rock of the Orijärvi aureole is composed chiefly of cordierite and anthophyllite.

Before entering into a description of this rock from the Orijärvi field, where the contact-rocks are very non-homogeneous, and usually contain much quartz or biotite as accessories, we shall first give a description of a locality where the rock, broadly speaking, consists exclusively of the two above minerals.

Cordierite-anthophyllite-rock near the farm of Träskböle in the parish of Perniö.

In the middle part of the leptite belt, near its northern boundary towards the large granite area, the leptitic rocks offer a rather monotonous appearance. They are gneissose, their primary features are entirely obliterated, and amphibolitic layers form the only variation. In the neighbourhood of the farm of Träskböle amphibolites also occur very rarely, and the rock is widely built up of leptitic gneiss.

Here one finds a mass of cordierite-anthophyllite-rock (fig. 33). This locality is situated about one km North of the farm of Träsk-

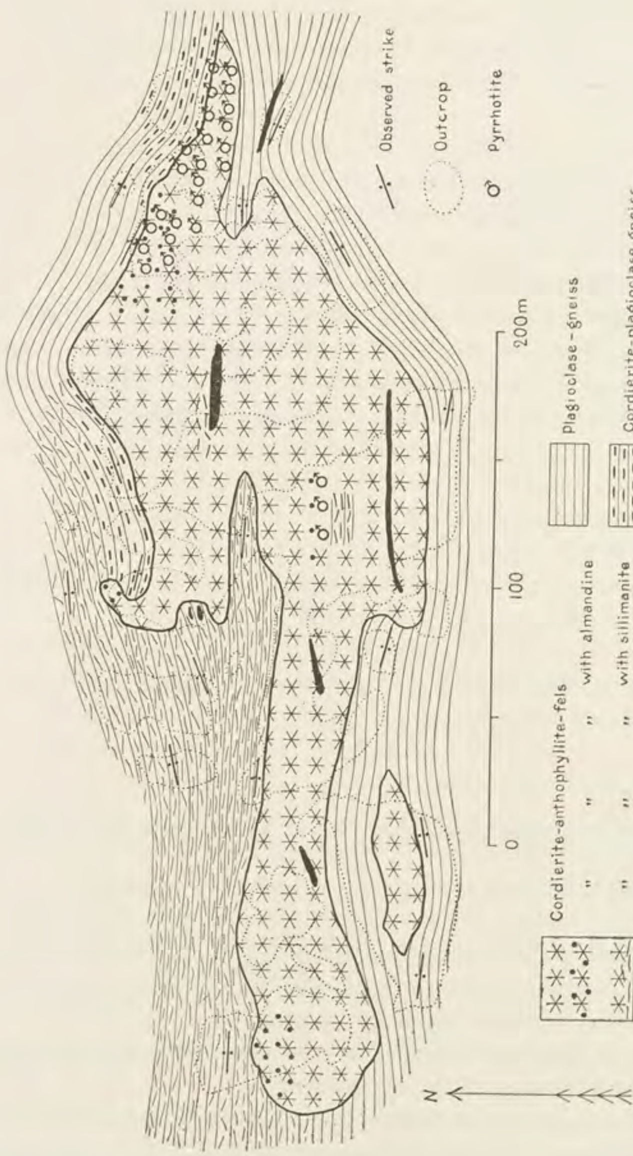

Fig. 33. The occurrence of cordierite-anthophyllite-rock near Träskböle.

böle, near a cottage named Norrbacka. The rock forms a plateau-like hillock whose slopes strictly coincide with the boundaries of the rock-area in question.

The rock (pl. VI) is characterized by radiating aggregates of a n t h o p h y l l i t e, measuring from 3 to 10 cm in diameter. The amphibole is of the usual fine-columnar habit. The interstices between these more or less regular aggregates are filled up by c o r d i e r i t e in large individuals, often many centimeters in diameter, but perfectly devoid of any crystallographic contours. Cordierite also fills up the interspaces between the radiating prisms of the amphibole. Smaller or greater amounts of brown b i o t i t e are also present in the rock. In certain parts of the mass the rock contains s i l l i m a n i t e, and in other considerable amounts of a l m a n d i n e are present. These varieties have been designated separately on the sketch-map, as well as parts where the rock contains p y r r h o t i t e.

The greatest part of the mass consists of a rock which contains but a trifling amount of biotite besides the main constituents. Such a rock was chosen for the quantitative investigation. As the rock was so coarsely crystalline, about ten kilograms of it were crushed up in order to make sure that its true composition should be represented by the analysis. This was made by the writer with the following results.

Table XXVIII.

		Mol.prop.	Mol. %	Norm		Mode	
SiO_2	48,00	0.800	51.4	Q	16.14 %	Cordierite	46.55 %
Al_2O_3	18,62	.182	11.7	Ab	2.10	Anthophyllite	47.62
Fe_2O_3	1,07	.007	0.4	An	2.50	Ilmenite	3.27
FeO	16,18	.225	14.6	Cor	17.24	Hematite	0.93
MnO	0,13	.002		Σ sal	37.98	Pyrrhotite	0.15
MgO	11,85	.296	19.0	Hy $MgSiO_3$	29.60	Apatite	0.39
CaO	0,64	.012	0.8	Hy $FeSiO_3$	25.48	Quartz	1.40
Na_2O	0,23	.004	0.3	Mt	1.62		100.31
K_2O	0,01	.000	—	Pyrrhotite	0.15		
TiO_2	2,06	.026	1.7	Il	3.95		
P_2O_5	0,09	.001	—	Apatite	0.34		
V_2O_3	0,04	.000	—	Σ fem	61.14		
Cr_2O_3	none	—	—		99.12		
Fe_7S_8	0,15	.002	—				
H_2O	1,50	—	—				
	100.57		99.9				

Osann's system:	s	A	C	F	a	c	f	k	T
	52.7	0.3	0.8	33.3	0	0.5	19.5	1.20	10.9

The mode was calculated from the analysis of the rock and those of the chief constituents, quoted below. As seen, the biotite does not appear, though it was observed megascopically in the specimen. The small percentage of potash indicates that the amount of the mica must be insignificant. The percentages of Al_2O_3 in the anthophyllite, in the cordierite and in the rock itself were used as starting points in the calculation. The excessive silica in the rock was considered as quartz, and the excessive titanium dioxide and ferric oxide were presumed to enter into the ilmenite. The analyses of cordierite and anthophyllite were made by the writer with the following results. Under III are given the percentages of those oxides in the rock which, according to the chosen method, could be calculated from the mineral-analyses, as well as the figures obtained from the rock-analysis. The agreement of the two sets of figures is a proof of the relative exactness of the analyses.

Table XXIX.

	I. Cordierite			II. Anthophyllite		III. The rock.	
	%	Mol.prop.	Mol.prop. SiO_2 = 5,000	%	Mol.prop.	Calculated	Determined
SiO_2	49.51	0.820	5.000	50.10	0.833	—	—
Al_2O_3	32.46	.318	1.972	7.35	.072	—	—
Fe_2O_3	0.29	.002		none	—	—	—
FeO	6.51	.091	2.012	22.86	.318	15.29	16.18
MnO	0.10	.001		0.25	.003	0.21	0.13
MgO	9.60	.238		16.64	.416	12.27	11.85
CaO	none	—		0.60	.011	0.58	0.64
Na_2O	—	—		0.54	.009	0.25	0.23
K_2O	—	—		none		—	—
TiO_2	none	—		0.73	.009	—	—
V_2O_3	—	—		0.09		—	—
H_2O	1.07	.059	0.360	1.15	.064	—	—
	99.54			100.31			

For the analysis of the c o r d i e r i t e, the sample was taken from an individual crystal, on which also the optical examination was carried out. This specimen was free from quartz. The piece was crushed in a diamond mortar, and from the powder the cordierite was obtained in a very pure form by repeated treatment with Thoulet's solution.

The cordierite is almost unaltered. Only by means of high power objectives is it possible to observe some small groups of muscovite scales along cracks. It contains many microscopic inclusions, the bulk of which are tabular crystals of ilmenite (cf. below). Further, there are rounded grains of quartz, measuring 0,03 to 0,2 mm in diameter, and still much smaller rounded short-prismatic crystals of apatite, surrounded by yellow pleochroic halos. Finally, minute prisms of anthophyllite are always visible even in the purest cordierite.

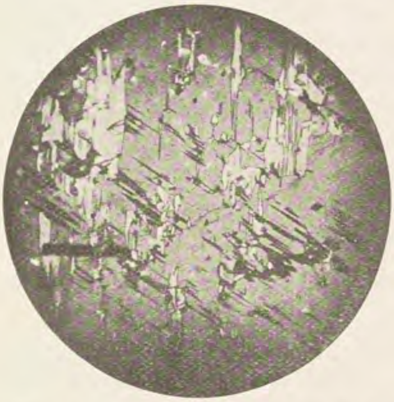

Fig. 34. Polysynthetic twinning in cordierite. Section ⊥ c. Crossed nicols. Magnified 50 diam.

Fig. 35. Cross-shaped lamellae in cordierite. Section ⊥ c. Crossed nicols. Magnified 50 diam.

Most of the individuals are simple crystals, but a few were found which show a polysynthetic twinning, resembling that of plagioclase. There are always two systems of parallel lamellae intergrown with a third individual crystal which forms the matrix of the two others (fig. 34). All three are twinned repeatedly with 110 as twinning plane. In most cases the lamellae are flattened in this direction; thus 110 is also the composition face. But sometimes the lamellae send out ramifications which are flattened in the direction of 130 (fig. 35). This face is, of course, no twinning plane, nor can it strictly be the composition face between the matrix and the lamellae. This will be evident if we consider that in cordierite crystals the angle 110 : $\bar{1}10$ = 90° 50′. Hence, in two crystals twinned on 110, the faces 130 are not parallel but form an angle of 1° 40′. In other cases the composition faces are curved and irregular.

The megascopical colour of the cordierite is bluish grey. Pleochroism is distinct in thick sections: $\mathfrak{b}$ = blue violet > $\mathfrak{c}$ = violet brown $\mathfrak{a}$ = light brown. The indices of refraction were determined with prisms. Prism I had one side ⊥ (010) and the refracting edge ∥ $\mathfrak{b}$ and in prism II one side was ∥ (010) and the refracting edge ∥ $\mathfrak{a}$. The results were:

	I	II	Average
α_{Na}	—	1.5373	1.537
α_{Li}	—	1.5351	1.535
β_{Na}	1.5441	1.5427	1.543
β_{Li}	1.5422	1.5411	1.542
γ_{Na}	1.5484	—	1.548
γ_{Li}	1.5452	—	1.545

From the averages the axial angle was calculated:

$$2\,V_{Na} = 84^\circ\ 16'.$$

The obtuse axial angle in methylene iodide, measured in a plate ∥ (010), was:

$$2\,I_o = 84^\circ\ 24'.$$

From this value we get:

$$2\,V_a \quad 81^\circ 28'.$$

The somewhat disagreable values of the indices of refraction and of the axial angle probably are due to a non-homogeneity of the cordierite, rather than to errors in the determinations.

Specific gravity was determined with Thoulet's solution and a Westphal's balance. The result was δ=2,588.

The analysis leads to the formula $(Mg,Fe,Mn)_2\ (Al,Fe)_4Si_5O_{18}$. There have been many different opinions among mineralogists, as to the nature of the water contained in the cordierite. Farrington [1]) regards it as constitution water and writes the formula

[1]) *Am. J. Sc.* 43, p. 13, 1892.

$H_2Mg_4Al_5Si_{10}O_{37}$, now generally accepted in this form. The latest investigations, however, do not confirm this result. Weibull [1] points out the fact that the water, at rising temperature, is expelled gradually, and not at any certain point. Zambonini [2] remarks, moreover, the very variable percentage of water in quite unaltered cordierites (Orijärvi, H_2O = 1.69 %, Bamle, H_2O = 4.09 %). The analysis of the Träskböle cordierite shows a percentage of water far below that required by Farrington's formula (1.48 %). Unfortunately the determination (with a Penfield tube) was made in a quantity of only about 0.5 gr, and the material was too scarce to allow any repetition of it.

The anthophyllite was separated from the coarsely crushed rock powder which was used for the rock-analysis. Small pieces of the amphibole were selected by hand, crushed, sifted and washed to form a powder of uniform grain, less than 0.2 mm in diameter. From this powder greater part of the ore minerals was separated by means of methylene iodide in which the amphibole floated. Subsequently the liquid was diluted with ether until the amphibole sank, while the cordierite and quartz floated. After repeating this procedure three times the mineral was boiled during ten minutes with diluted nitric acid, in order to remove traces of apatite. It was now very pure, containing only a few particles of ilmenite, whose bulk could not be more than about 0.1 % at most.

In the eastern part of the mass, where the rock is garnetiferous and rich in pyrrhotite, the anthophyllite is darker than elsewhere. As it seemed interesting to compare the composition and the optical properties of the differently coloured varieties, I made an analysis of the darker variety also. The sample was prepared in the same way as the former one. In table XXX we give the result of this analysis and the former one once more for comparison, besides some analyses of orthorhombic amphiboles from other localities. I. the darker, and II. the paler anthophyllite from Träskböle, III. anthophyllite from Stansvik, near Helsingfors [3], IV. anthophyllite from Franklin, N. C.[4], V. gedrite from Fiskernäs, Greenland. [5]

[1] *G. F. F.* **22**, p. 41, 1900.

[2] *Atti R. Accad. delle Scienze Fis. e Mat. di Napoli*, 1908, **16**, p. 1—127; ref. Zs. Kr. **49**, p. 84, 1911.

[3] Average of two analyses made by O. Rosengren and K. Stadius, published by Wiik, *Zs. Kr.* **2**, p. 498, 1878.

[4] S. L. Penfield, *Am. J. Sc.* **40**, p. 394, 1890.

[5] N. V. Ussing, *Zs. Kr.* **15**, p. 610, 1890.

Table XXX.

	I		II		III	IV	V
	%	mol.prop.	%	mol.prop.			
SiO_2	48.00%	0.800	50.10%	0.833	51.90%	57.98%	46.18%
Al_2O_3	7.63	.075	7.35	.072	9.00	0.63	21.78
Fe_2O_3	1.11	.007	none	—	—	—	0.44
FeO	26.11	.363	22.18	.318	20.53	10.39	2.77
MnO	0.18	.003	0.25	.003	0.33	0.31	—
MgO	12.66	.316	16.64	.416	16.84	28.69	25.05
CaO	0.64	.011	0.60	.011	1.57	0.20	—
Na_2O	1.21	.019	0.54	.009	—	—	2.30
K_2O	0.24	.002	none	—	—	—	—
TiO_2	1.00	.013	0.73	.009	—	—	—
V_2O_3	n. d.	—	0.09	—	—	—	—
H_2O	1.09	.056	1.15	.064	—	1.79	1.37
	99.87		100.54		100.17	99.99	99.89

Among the orthorhombic amphiboles which consist chiefly of isomorphous mixtures of the silicates $(Mg,Fe)SiO_3$ and $(Mg,Fe)\,Al_2SiO_6$, the one from Franklin presents the former in an almost pure form, and that from Fiskernäs is the richest hitherto analyzed in the latter, containing about 36 mol. % $(Mg,Fe)Al_2SiO_6$. The anthophyllites from Träskböle stand midway between these two extreme varieties and seem to be almost identical with the only other analyzed example from Finland, i. e. the anthophyllite from Stansvik. Furthermore, the minerals of both series consist of mixtures of ferro and magnesium silicates. But, besides these compounds, there are alkali silicates, in which hydrogen replaces part of the alkali metals. Most authors, who have studied the orthorhombic amphiboles, have been inclined to assume that water is combined chemically in them. Analyses I and II also prove that so is the case. If the water were not taken into account, the silica would be in excess of the monoxides and alkalis. Weibull [1] assumes the glaucophane molecule, $NaAlSi_2O_6$, to enter into the anthophyllites as a further isomorphous compound. Our analyses are more in favour of the assumption that alkalis and water might replace part of the monoxides.[2] Thus interpreted the analysis of the pale antho-

[1] *G. F. F.* **18**, p. 383, 1896.
[2] Cf. N. V. Ussing, *Zs. Kr.* **15**, p. 611, 1889.

phyllite gives the molecular ratio $(SiO_2,TiO_2) : (\overset{II}{R}O,\overset{I}{R}_2O) = 1 : 0.975$, while that of the darker variety gives $1 : 0.947$.[1] Whether alkalis and water are present in the aluminous or non-aluminous component, cannot be ascertained. Supposing them to be distributed equally between both, the ratio $\overset{II}{R}SiO_3 : \overset{II}{R}\,\overset{III}{R}_2SiO_6$ in the paler variety is 91 : 9 and in the darker 89 : 11.

The anthophyllites from Träskböle show the usual optical orientation: $a = \mathfrak{a}$, $b = \mathfrak{b}$, $c = \mathfrak{c}$; the optical character is positive and the axial angle is large, probably between 70° and 80°. Unfortunately I was not able, with the means at my disposal, to determine it exactly because of its finely fibrous structure. Two indices of refraction were determined in each variety by the immersion method with the following results:

Pale anthophyllite	$\beta_{Na} = 1.653$;	$\gamma_{Na} = 1.776$
Dark »	$\beta_{Na} = 1.662$;	$\gamma_{Na} = 1.767$

These data show that the variability of the refringence corresponding to the variations in the amount of ferrous iron is very sensible.

In the darker variety a faint pleochroism is noticeable in thin sections, while the paler is colourless. Both show the same tints; the scheme is: $\mathfrak{a}$ = pale clove brown, $\mathfrak{b}$ = clove brown, $\mathfrak{c}$ = dark greyish brown.

In a minute cleavage splinter the angle $110 : 1\bar{1}0 = 55° \, 10'$ was measured, giving the ratio:

$$a : b = 0.5224 : 1.$$

The anthophyllite is perfectly unaltered. It contains inclusions of the same kind as the cordierite.

The specific gravity was determined with methylene iodide and a Westphal's balance:

Pale anthophyllite	$\delta = 3.17$
Dark »	$\delta = 3.22$

[1] The agreement of the analyses with the formula would be closer, if part of the alkalis were calculated as glaucophane. But there are other possibilities: part of the monoxides may be replaced by aluminous radicals, or the mineral may contain fluorine which was not determined. At any rate, it is evident that the ferro-magnesium amphiboles are no more simple metasilicates than the amphiboles of the actinolite-hornblende series. Vide: S. L. Penfield and F. C. Stanley, *Am. J. Sc.* **23**, 1907.

I l m e n i t e is the most important accessory. According to the analyses, the oxide ores contain 22 % Fe_2O_3 and 78 % $FeTiO_3$. From another specimen — the one used for the cordierite-analysis — I separated 100 mg pure ore mineral which in this case contained no sulphides. In this sample Fe_2O_3, TiO_2 and MgO were determined. Considering the mineral as a mixture of Fe_2O_3, $FeTiO_3$ and $MgTiO_3$, the result was:

Fe_2O_3	45.81 %
FeO	24.96 »
TiO_2	28.09 »
MgO	0.14 »
	99.00 %

Fig. 36. Tabular crystals of ilmenite, enclosed in cordierite. Magnified 16 diam.

Fig. 36 shows the forms of the ilmenite occurring as inclusions in the cordierite. It appears as tabular crystals with dominant (0001) and small, mostly rounded rhombohedral faces. Generally the crystals do not show any regular arrangement, but in the case illustrated by the figure, all the sheets are arranged at right angles to (010) of the cordierite.

Such tabular or more irregularly formed crystals occur as inclusions in all the constituents of this rock. During the preparation of the samples for analyses of the different minerals, such crystals were several times separated and always found to be ilmenite.

The a l m a n d i n e when present in the cordierierite-anthophyllite-rock always occurs in the form of rounded crystals, from 5 to 10 mm in diameter. At the western end of the mass the rock grades into an almandine-biotite-rock, the typical minerals disappearing; here the crystals attain a size of 5 cm in diameter.

I made an analysis of comparatively pure selected splinters of this garnet, which, however, contained some enclosed quartz and iron ores. As separation seemed impossible without much labor, I determined in that impure material only the most important compounds:

SiO_2	39.21 %
Al_2O_3	17.07 »
FeO	33.79 »
MnO	2.00 »
CaO	1.98 »
MgO	2.78 »
TiO_2	2.19 »
	99.02 %

No direct determination of FeO was made. The analysis gives the ratio $\overset{II}{R}O : \overset{III}{R}_2O_3 = 3 : 0.87$ instead of 3 : 1, which means that two or three percents of Fe_2O_3 must be present.

There is a peculiarity in the arrangement of the inclusions in the almandine which deserves attention from the geological point of view. Between areas very rich in small inclusions there are parallel but somewhat curved streaks without any inclusions. T h e d i r e c t i o n o f t h e s e s t r e a k s i s t h e s a m e a s t h e s t r i k e o f t h e n e i g h b o u r i n g l e p t i t e s.

The almandine is red, the colour being discernible also in thin sections. It is perfectly isotropic.

The crystals are surrounded by a narrow zone containing merely cordierite and quartz but no anthophyllite. Instead of the latter there is chlorite (p e n n i n i t e). It is almost uniaxial, and shows negative character and a grass green absorption colour for rays vibrating parallel to $\mathfrak{b}$ and $\mathfrak{c}$.

B i o t i t e is always present as thin flakes. It is of a dark brown bolour with the usual pleochroism, and nearly uniaxial. The scales are often one or two cm in diameter.

S i l l i m a n i t e is one of the most typical accessories of the cordierite-anthophyllite-rock of Träskböle. In the contact-facies, which will be described later on, this mineral displays the characteristics of the fibrolite, but in the coarsely crystalline cordierite-anthophyllite-rock it occurs as crystals of unusual dimensions. The largest one observed measured $9.5 \times 5 \times 5$ cm. These cystals are always surrounded by a shell of cordierite and were never found in contact with anthophyllite, Where the crystals of sillimanite are frequent, no anthophyllite whatever is present. In such portions quartz is more abundant than elsewhere.

As this mineral is not soluble in hydrofluoric acid, it was easily separated from the adhering cordierite and quartz by treating the powder, which had already been freed from ilmenite by means of a heavy solution, with strong hydrofluoric and sulphuric acid. The sample now seemed pure, containing, however, single enclosed ore grains. The result of a chemical analysis was:

Fig. 37. Sillimanite, surrounded by cordierite (black). 3/4 nat. size.

			Mol. prop.
SiO_2	36.90	%	0.6109
Al_2O_3	62.50	»	0.6115
Fe_2O_3	0.41	»	
TiO_2	0.12	»	
Loss on ignition	0.13	»	
	100.06	%	

The small amounts of iron and titanium are evidently derived from ilmenite. The mineral consists of very pure Al_2SiO_5.

The forms of the crystals are ellipsoidally rounded and irregular (fig. 37), here and there, however, showing plain faces of the prismatic zone. They are surrounded by a shell of cordierite, from one to ten mm thick. Cleavage parallel to (100) is very distinct. The cleavage-planes are striped in the direction of axis c, owing to the fact that the large crystals are not strictly individual, but are composed of a system of subparallel prisms. There are some larger individual prisms, up to 3 mm in breadth and more, and the interspaces between them are filled by a fine-columnar mass. In sections || (001) the directions of extinction in neighbouring individuals are usually nearly parallel, so that the lack of individuality can just be observed. In some cases the divergence is clearly noticeable, though seldom as much as 3°. The different individual crystals limit each other either with plain or with curved faces (fig. 38). In the former case their transversal sections are rhombs. This form becomes especially apparent when the mineral is bounded by cordierite, which appears here and there between the lamellae. The latter mineral, too, shows a subparallel arrangement. In sections || (001) of sillimanite all cordierite grains are also cut almost || (001), showing a negative acute bisectrix. Thus, axis c of the cordierite is parallel to c of the sillimanite, but otherwise the former shows no regular arrangement: The direction of extinction is quite variable in different grains. The cordierite shell which surrounds the sillimanite is also arranged in the same way.

Fig. 38. Sillimanite. || (001). Crossed nicols. Magnified 16 diam.

The sillimanite contains inclusions of ilmenite and apatite. The former fills up interstices in the sillimanite in the same way as does the cordierite, i. e. the ore mineral is perfectly xenomorphic here. Its identity with the ilmenite was proved by a chemical test. A p a t i t e occurs as small rounded prisms arranged parallel to axis c of the matrix crystal. Still further, the sillimanite contains fine fibrous fibrolite showing no regular arrangement of the fibres.

The hardness of the sillimanite is between 6 and 7. Its specific gravity was determined by means of methylene iodide and a Westphal's balance: $\delta = 3.191$.

The mineral is perfectly colourless and translucent in as thick sections as 5 mm. Two indices of refraction (α and γ) were determined with a prism cut so that the refracting edge was || b and one side || (100). Further, it was determined with the Babinet compensator that $\beta - \alpha = 0.0013$. Thus were obtained:

$\alpha_{Na} = 1.663$ $\beta_{Na} = 1.664$ $\gamma_{Na} = 1.684$
$\alpha_{Li} = 1.660$ — $\gamma_{Li} = 1.681$

From the indices of refraction the positive acute axial angle may be calculated:

$$2\,V = 28^\circ\ 45'.$$

A direct determination with a Klein's lens gave

$$2\,E = 49^\circ\ 30',$$

which, according to the graphical solution of the equation sin i = n sin r, leads to

$$2\,V = 29^\circ.$$

The contacts of the cordierite-anthophyllite-rock near Träskböle.

As has been mentioned, the surrounding area of the anthophyllite-cordierite-rock is very uniform, and it is generally underlain by leptitic biotite-plagioclase-gneisses. Examples of their composition were given above (page 148). In the immediate vicinity of the occurrence under consideration the rock still shows its usual characters. Thus, a few meters north of the western end of the greatest lens, the gneiss is composed of quartz, plagioclase, biotite and small amounts of microcline. In the plagioclase $\beta = \omega$ of the quartz, and the maximum extinction angle in sections $\perp$ (010) = 7°, corresponding to $Ab_{76}An_{24}$. Another specimen, from immediately north of the eastern corner of the rock-mass, contains plagioclase which shows, in sections $\perp$ (001) and (010), extinction angles of + 23° (5 observations), corresponding to $Ab_{58}An_{42}$. The other constituents are quartz, biotite and cordierite. The transition of this rock into the cordierite-anthophyllite-rock takes place gradually within a narrow zone.

At the southern boundary of the lens, the contact-phenomena were studied more in detail. Approaching the boundary-line, a monoclinic amphibole appears besides the anthophyllite, and cordierite gives place to plagioclase. At a certain stage the intermediate rock is composed mainly of monoclinic amphibole and plagioclase. Further south quartz increases in quantity, and biotite gradually takes the place of the amphibole. Thus the anthophyllite-cordierite-rock grades into a typical plagioclase-gneiss, the transition zone being only one meter broad.

The optical properties of the monoclinic amphibole did not determine whether it is actinolite or monoclinic ferro-magnesium amphibole. A chemical investigation proved that it belongs to the latter. A sample of the mineral, separated from the coarsely ground rock powder by means of heavy solutions, was partially analyzed with the following results:

FeO	21.47 %
MgO	17.85 »
CaO	0.54 »
Na_2O	0.27 »

A close accordance with the analyses of the rhombic amphiboles is quite remarkable.

This monoclinic amphibole presents a long-prismatic habit closely resembling that of the anthophyllite. In thin sections it is almost colourless. a = $\mathfrak{a}$; b = $\mathfrak{b}$; c : $\mathfrak{c}$ = 17.5°. In a section ‖ (010) two indices of refraction were determined by the immersion method, resulting in:

$$\alpha_{Na} = 1.641$$
$$\gamma_{Na} = 1.668$$

Thus $\gamma - \alpha = 0.027$; this value is often obtained in actinolites. The optical character is positive, and 2 V large, probably between 80° and 85°. The mineral is idioblastic on (110).

Twinning, with the twinning plane parallel to (100), occurs occasionally.

Another phenomenon, which at first sight resembles the twinning, is of quite a peculiar character: T h e m o n o c l i n i c a m p h i b o l e o c c u r s i n h o m o a x i a l i n t e r g r o w t h w i t h t h e a n t h o p h y l l i t e. This phenomenon may best be seen in sections ⊥ (100) which, if the monoclinic amphibole is not twinned, are usually composed of three lamellae, of which the middle one shows oblique extinction, while in the two others extinction is parallel to the elongation (pl. IV, fig. 1. Cf. pl. V, fig. 1 and 2). The composition face is parallel to (100), being usually quite plain, like the composition faces of the twinned lamellae; sometimes the rhombic amphibole has developed as an outer shell all around the crystals. More rarely the rhombic amphibole forms lamellae in the monoclinic variety.

On the whole, the amount of anthophyllite was so inconsiderable that it could hardly affect the value of the chemical determinations.

So far as can be concluded from the partial analysis, this monoclinic amphibole may be chemically identical with the anthophyllite. In the section used for the determination of the above refractive indices of the monoclinic amphibole, α and γ respectively seemed identical in both modifications, between the limits of the accuracy of the immersion method (in this case about $\pm$ 0.0015). The identity, however, cannot be exact, as the birefringence is higher in the monoclinic than in the rhombic variety: the former shows, in sections || (010) of the usual thickness of thin slides, a green interference colour of the second order, the adjacent anthophyllite being blue. The difference in the birefringence can be estimated at 0.002 or 0.003. If γ were exactly identical in both modifications, the difference in α would be so great that it could certainly be noticed by means of the immersion method, and so would γ be conspicuously different, if α were identical in both. Hence α in the anthophyllite is probably 0.001 or 0.0015 higher, and γ about as much lower than the corresponding refractive indices of the monoclinic amphibole. It would be of great interest to know whether β is exactly identical in both modifications or not, but this, of course, cannot be determined by means of the immersion method.

There has been some confusion in the nomenclature of the monoclinic ferro-magnesium amphiboles. A. Des Cloizeaux[1] introduced the name amphibole-anthophyllite, used by him originally for non-aluminous amphiboles, heteromorphous with the anthophyllite. Besides this rather illogical name, c u m m i n g t o n i t e [2] has been much used to designate those monoclinic ferro-magnesium amphiboles which correspond to the bronzite-hypersthene series. For magnesium metasilicate the name k u p f f e r i t e and for the ferro metasilicate g r u e n e r i t e have been fixed upon. We shall take the name cummingtonite [3] for the monoclinic ferromagnesium amphiboles which occur in the area under consideration and contain, so far as is known at present, considerable amounts of the ferrous as well as of the magnesian molecules.

The relations between cummingtonite and anthophyllite seem to offer great interest from a mineralogical point of view. If some more detailed future investigation proves them to have their physical properties as nearly identical as those of enstatite and clino-

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[1] »Nouvelles recherches», XVIII, p. 541 and 624, quoted in »Manuel de Minéralogie», tome second, p. XX, 1874.

[2] Dewey, *A. J. Sc.* 8 p. 59, 1824, quoted by Dana, »System of Mineralogy» p, 386, 1892. The name cummingtonite has priority before amphibole-anthophyllite.

[3] In the following, the intergrowth of monoclinic and rhombic amphiboles will frequently be called *cummingtonite & anthophyllite.*

enstatite, or those of orthoclase and microcline, new elucidation on the problem of polysymmetry (Groth) will be afforded.

From the observation of the present writer it is quite evident that the anthophyllite and cummingtonite occur in the manner of two different mineral species, and there is absolutely nothing to suggest that the anthophyllite would be composed of submicroscopical twinned lamellae of the monoclinic amphibole.

A study of the cummingtonite-plagioclase-rock proves that its composition lies outside that of those rocks between which it occurs. A slice of it contained about 48 vol. % plagioclase, 40 % cummingtonite & anthophyllite, 10 % biotite, 2 % ilmenite and no quartz. The plagioclase, well twinned according to the albite and pericline laws, showed in several sections ⊥ (010) and (001) an extinction angle of +25° thus having the composition $Ab_{55}An_{45}$. From these data it may be calculated that the rock contains about 4.0 % CaO, i. e. more than I have ever found in the plagioclase-gneisses of this region. The plagioclase is more calcic than any one found in the surrounding leptites. The conclusion is likely to be drawn that this boundary rock had originally been an amphibolite, whose composition had been changed by the metamorphism. Such cummingtonite-amphibolites also occur in the Orijärvi field.

At the northern side of the rock-mass the contact-phenomena are of a different character. Firstly, the anthophyllite disappears and quartz becomes abundant, so that a quartz-cordierite-rock results. A similar variety also occurs as a lens inside the main mass. Large crystals of s i l l i m a n i t e are found in this variety. C o r d i e r i t e still appears as large xenoblasts, two or even more cm in diameter. In them numbers of rounded grains of quartz are enclosed, accompanied by f i b r o l i t e. Occasional o l i g o c l a s e completes the list of constituents. Towards the North m i c r o c l i n e becomes the dominant constituent besides quartz and biotite, the cordierite disappearing gradually. The rock is here very distinctly foliated, owing to a parallel arrangement of the scales of mica and the lenticular grains of microcline. The transition of this rock into the typical plagioclase-gneiss could not be studied completely because of the absence of outcrops, but the belt must be rather narrow, as about twenty meters from the cordierite-bearing rocks a plagioclase-gneiss is exposed, here containing also hornblende.

As we saw, the composition of the intermediate rock at the northern side of the cordierite-anthophyllite-rock is no more an average of this rock and the plagioclase-gneiss, than the southern boundary rock.

We shall discuss the genesis of the cordierite-anthophyllite-rock in connection with related rocks in the Orijärvi field. Here only a few remarks on its geological relations to the neighbouring rocks may be given.

The composition of the cordierite-anthophyllite-rock is no more that of any ordinary sediment than of any common igneous rock. One would be inclined to explain it as a product of pneumatolytic contact-metamorphism. In the Orijärvi field such an explanation seems natural, as those rocks occur there as an aureole surrounding a granite-mass. But where is the igneous body which has given rise to the Träskböle rock? The boundary of the microcline-granite lies almost one kilometer to the North, and this rock is nowhere in immediate contact with the cordierite-anthophyllite-rock. Moreover, there are some evidences that the latter is of an earlier date than the granite. Pegmatite dikes, probably connected genetically with the microcline-granite, intersect the cordierite-anthophyllite-rock in the manner of later intrusions. The cordierite-anthophyllite-rock is surrounded by gneisses whose strike is conformable with the boundary-lines of the lens. A parallel structure may be observed in the rock-mass also, especially in the boundary zones. The almandine-biotite-rock of the western part of the mass and the sillimanite-bearing portions are very distinctly schistose. The recrystallization must have taken place under stress, which in this area has been exerted only before the consolidation of the microcline-granite.

Consequently, if we want to regard the Träskböle cordierite-anthophyllite-rock as a product of contact-metamorphism, we must assume that its parent rock is not in sight, but that active vapors had risen from beneath, fed by an abyssal magma which has not yet been exposed at the earth's surface. Of all reasonable assumptions, the one that the rock in question is connected with some igneous body related to the oligoclase-granites, seems the most probable.

The nearest rock-mass which belongs to the oligoclase-granite group is formed of quartz-diorite and occurs about 6 km to the West, on the island of Kimito. Continuing in an easterly direction from this rock-belt, there is a series of occurrences of ores and rocks which resemble the occurrences round the Orijärvi granite. Near Strömma andradite-skarn and magnetite occur. Half a kilometer to the West from Norrbacka sphalerite has been found. Here the ore occurs partly in pegmatite, but is probably older than this, as was pointed out by the writer in another paper (**43**). An occurrence of galena is situated near the farm of Skoila east of Norrbacka; the ore occurs here immediately in the leptitic gneiss. Finally, the cordierite-anthophyllite-rock itself closely resembles numerous occurrences in the vicinity of the Orijärvi granite. The Träskböle rock also contains sulphide minerals, namely pyrrhotite.

Cordierite-anthophyllite-rock in the Orijärvi aureole.

Cordierite-anthophyllite-rock devoid of plagioclase is of common occurrence in the Orijärvi area, but it does not form such great homogeneous bodies as the lens of this rock near Träskböle. Usually

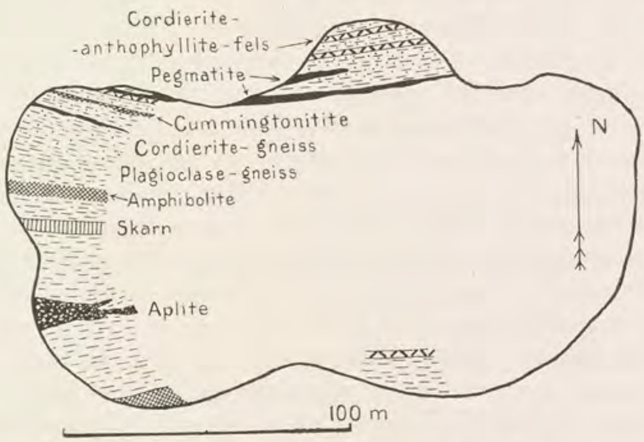

Fig. 39. Sketch-map of the island of Vähäholma, Lake Määrijärvi.

the occurrences are lenticular or sill-shaped, their thickness is only a few meters, and they are intercalated with other cordierite-bearing rocks.

The island of Vähäholma.

On the island of V ä h ä h o l m a in Lake Määrijärvi, south of the Orijärvi granite, cordierite-bearing rocks form layers of various composition (fig. 47). On the northern shore the rock is rich in biotite, but grades southward into a variety which consists almost exclusively of anthophyllite. Farther south a layer of cordierite-gneiss with anthophyllite follows, and again cordierite-anthophyllite-rock containing abundant biotite. In the northwestern corner of the island a bed is exposed, less than ½ m thick, composed merely of anthophyllite and cordierite with small crystals of almandine and magnetite, the latter developed as octahedra. This rock displays characters nearly identical with those of the cordierite-anthophyllite-rock of Träskböle. The anthophyllite is formed as radiating aggregates of three of four cm in diameter, and the cordierite fills up their interstices.

Excepting that magnetite is present instead of ilmenite, the constituent minerals are the same as in the Träskböle rock, only the proportion of anthophyllite is larger. This layer is bordered by a dike of pegmatite, which is doubtless of an essentially later date and has converted the adjacent cordierite-anthophyllite-rock to a mass composed chiefly of biotite.

The northern shore of Lake Määrijärvi.

Some lenticular masses of cordierite-anthophyllite-rock are exposed in the shore-cliffs at the northern end of Lake Määrijärvi. On the water-worn surface the large xenoblasts of cordierite protrude from the more eroded anthophyllite, giving the rock that knotty appearence which is characteristic of all coarsely crystalline cordierite-anthophyllite-rocks. The prisms of anthophyllite are irregularly arranged, not in radial bunches as in the former cases. Megascopically this rock resembles the plagioclase-bearing cordierite-anthophyllite-gneisses, but no plagioclase was detected under the microscope.

This rock is composed of cordierite, anthophyllite, quartz, biotite, apatite, pyrite and zircon, the quantitative proportions being indicated by the above order. A n d a l u s i t e occurs occasionally as red-coloured crystals, sometimes measuring 1 cm in diameter. They are surrounded by cordierite, being nowhere in immediate contact with the anthophyllite.

The cordierite-anthophyllite-rock fades away into the andalusite-bearing gneissose rock which surrounds it. Towards the boundaries, the amount of biotite increases, that of anthophyllite diminishes. The xenoblasts of cordierite become smaller and finally disappear. Small elongated bodies of this rock appear in the andalusite-bearing rock.

The foliation of the cordierite-rock is feebly marked by the parallel arrangement of the anthophyllite and biotite. The strike of the adjacent gneissose rock is not more marked.

Midway between the Iilijärvi mine and the cottage of Grönqvist (fig. 52, p. 235) the cordierite-anthophyllite-rock contains cordierite as the principal constituent. Quartz is present in large amount as inclusions in the xenomorphic cordierite and also as a granular mass. The radiating aggregates of anthophyllite are usually one or two cm only in diameter. In this rock tabular ilmenite occurs frequently. Occasionally gahnite is present in large quantities as crystals of one mm or less in diameter, showing (111) and (110). Crystals of galena and irregular grains of sphalerite also occur. The last-mentioned mineral often fills up cracks or occurs as small stringes, which might suggest the idea that they are products of later infiltration, whilst the gahnite crystals are included in the cordierite and are in no way suggestive of any epigenetic origin.

Going from the last-named locality towards the Iilijärvi mine, one meets with several outcrops of cordierite-anthophyllite-rock containing smaller or greater amounts of sulphide minerals. The most southern of the old pits at the Iilijärvi mine is made in such a rock, composed of cordierite, monoclinic amphibole, quartz, biotite, almandine, chlorite, apatite, ilmenite, pyrite, arsenopyrite and chalcopyrite. The amphibole resembles the anthophyllite and is probably cummingtonite. The sulphides are included in the various chief constituents. The pyrite is euhedral, while the other ore minerals occur as irregular grains.

Cordierite-anthophyllite-rock at the Orijärvi mine.

The greater part of the Orijärvi mine has been made in cordierite-anthophyllite-rock containing ore minerals. At the surface similar rocks are exposed at numerous points in the vicinity of the mine. The adjacent rocks are cordierite-anthophyllite-gneiss, cordierite-gneiss, quartz-cordierite-rock and, in the mine, tremolite-skarn. The rock in question occurs as lenticular bodies. When free from plagioclase, it usually presents the typical structure characterized by the star-shaped aggregates of anthophyllite. Beautiful examples of such a rock are exposed in front of the farm building of Orijärvi. The thickness of a single lens is usually only a few meters, sometimes less than one meter. A great number of specimens and diamond drill cores of the rocks from the mine were examined microscopically.[1] It was found that the quantitative proportions of the different constituents vary between wide limits. Usually cordierite is in excess of the amphibole, but at times the proportion is reversed. Some specimens are free or nearly free from quartz, in others quartz is present in greater amount than the typical minerals, so that the rock displays a quartzitic character (»ore-quartzite»). Biotite is usually but not always visible. Besides the minerals already mentioned, the rock often contains c h l o r i t e (clinochlore). Ilmenite is frequently observed as sheet-shaped minute crystals limited by (0001) and (10$\bar{1}$1), enclosed in all the other constituents. Further, sulphidic ore minerals are mostly present. Their occurrence and origin will be the subject of discussion in another chapter.

In an outcrop north of the mining field, the rock is composed of anthophyllite, biotite, cordierite and ilmenite, the first-named being predominant. West of the Workmen's Association house a

[1]) For the greater part of these slices I am indebted to Mr O. Trüstedt.

narrow band was found to be composed almost exclusively of brownish grey anthophyllite. This »band» is almost dike-shaped, and only one or two dm in thickness.

The minerals of the cordierite-anthophyllite-rock in the Orijärvi field. The Orijärvi mine is renowned for the large and beautiful crystals of cordierite which are found there. This cordierite was first described in 1818 by J. Gadolin (1), who called it steinheilite, believing it to be a new mineral species. In 1821 Stromeyer (3) proved its identity with the dichroite (Haüy). Since that time, the Orijärvi cordierite has repeatedly been subjected to mineralogical and chemical investigation. The most important results may be quoted below.

A. Descloizeaux (13) determined the refractive indices and the axial angle:

$$\alpha_{or} = 1.5337;\ \beta_{or} = 1.5375;\ \gamma_{or} = 1.5400;\ 2E_{or} = 150° 28';\ 2V_{or} = 77° 57'.$$

Haidinger (7) ascertained the formula of pleochroism: a = $\mathfrak{b}$ = dark Berlin blue, b = $\mathfrak{a}$ = light Berlin blue, c = $\mathfrak{c}$ = reddish clove-brown.

Chemical analyses have been made by Stromeyer (3), v. Bonsdorff (4), Thomson (6), Schütz (8) and Dittrich (Sustschinsky, 41, p. 213). We may quote three of them (table XXXI).

Table XXXI.

	Stromeyer, 1821.	v. Bonsdorff, 1822.	Dittrich, 1912.
SiO_2	48.54	49.95	48.68
Al_2O_3	31.37	32.88	33.05
Fe_2O_3	—	—	0.42
FeO	5.69	5.00	4.41
MnO	0.70	0.03	0.03
MgO	11.30	10.45	10.06
CaO	—	—	0.12
K_2O	—	-	0.12
Na_2O	—	—	0.51
H_2O+	1.69	1.75	1.70
H_2O-			0.16
CO_2	—	—	0.44
	99.29	100.06	99.75

	Stromeyer	v. Bonsdorff	Dittrich
$RO_2 : R_2O_2 : RO$	5 : 1,904 : 2,200	5 : 1,981 : 2,029	5 : 2,016 : 1,942

Of these analyses that of v. Bonsdorff shows the closest accordance with the cordierite formula. Sustschinsky, who published the analysis made by Dittrich, does not give any account of the quality of his material. It seems probable that the rather considerable amount of alkalis may have been derived from impurities.

The crystals of cordierite in the Orijärvi mine occur in the ore-bearing cordierite-anthophyllite-rock. The crystallographic contours have developed only when the mineral is enclosed in chalcopyrite, sphalerite, pyrrhotite or quartz. It seems evident, that their euhedral form is not due to the the crystalloblastesis in the sense defined by Becke, but it must be a consequence of a certain order of crystallization, i. e. the cordierite is of an earlier date than the surrounding minerals. In numerous specimens it may be seen that the crystals protrude from the cordierite-anthophyllite-rock into the quartz and the ore-mass, quite in the manner of crystals which occur in drusy cavities.

Generally the c o r d i e r i t e in the cordierite-anthophyllite-rock of the Orijärvi region is xenoblastic, like that in the Träskböle rock. Sometimes it shows a tendency towards a long-prismatic crystalline form, as at the northern shore of Määrijärvi and, still more pronounced, on a cape on the western shore of that lake. In such cases, too, the anthophyllite has grown in the cordierite and is idioblastic towards it.

The colour of the cordierite is usually smoky grey, the bluish tinge having been only rarely observed; doubtless it is masked by the abundant enclosed grains of quartz, biotite and ore minerals.

In many cases all the indices of refraction in the cordierite were found to be lower than ω of quartz, but not always. Thus I obtained the following results in cordierite from the western shore of Lake Määrijärvi.

1) Quartz $\perp$ c; cordierite cut obliquely to all axes of ether vibration; parallel position:

$$\alpha' > \omega;\ \gamma' > \omega$$

2) Quartz ||c; cordierite || $\mathfrak{a}\,\mathfrak{b}$, parallel position:

$$\varepsilon < \beta;\ \omega < \alpha.$$

3) Quartz ||c; cordierite || $\mathfrak{a}\,\mathfrak{b}$; transversal position:

$$\beta > \omega;\ \varepsilon > \alpha.$$

Hence

$$1.535 > \alpha > 1.544 \text{ and}$$
$$\beta > 1.553.$$

The optical character being negative with a large axial angle, and the birefringence being somewhat lower than that of quartz, we may take for granted that

$$(\gamma - \beta) < (\beta - \alpha) \lesssim 0.006.$$

Thus α and β could be determined with an accuracy of $\pm$ 0,003:

$$1.553 > \alpha > 1.547, \text{ or } \alpha = 1.550 \pm 0.003;$$
$$1.559 > \beta > 1.553, \text{ or } \beta = 1.556 \pm 0.003.$$

These values are higher than what was found in the cordierite from Träskböle (p. 174) and also higher than what Des Cloizeaux found in the cordierite from the Orijärvi mine. This example shows that the refringence of the cordierite is considerably variable, doubtless depending upon the percentage of ferrous oxide.

The anthophyllite is greatly variable in colour and refringence (table XXXII):

Table XXXII.

Locality	Colour	FeO %	β_{Na}	γ_{Na}
Träskböle, Perniö	Dark greyish brown	26.11	1.662	1.676
»	Brownish grey	22.18	1.653	1.667
Kurksaari, Kisko	Dark brown, nearly black	—	—	1.675
Western shore of Määrijärvi	Dark brownish green	—	1.659	1.669
300 m north of Määrijärvi	Pale brownish grey	—	1.642	1.654
The Orijärvi mine	Pale greenish brown, nearly colourless	—	1.629	1.642

The darkest varieties show the strongest refringence and are probably richest in ferrous oxide. All examples examined were similar in showing a positive optical character and large axial angle. No correspondence between the axial angles and the colour or refringence could be detected. Thus the light variety from the Orijärvi mine mentioned in table XXXII showed, in sections $\perp$ an optic axis, a distinct curvature of the axial bar, while in another nearly colourless variety from the island of Paavoholma the curvature of the axial bar was almost unnoticeable. On the other hand, a very dark-coloured anthophyllite [1] which was distinctly pleochroic in thin sections ($\mathfrak{a}$ = pale yellow < $\mathfrak{b}$ = greenish grey < $\mathfrak{c}$ = bluish grey) showed around $\mathfrak{c}$ an axial angle decidedly smaller than 90°.

The data quoted in table XXXII show also a difference between the Orijärvi and the Träskböle anthophyllite: $\gamma - \beta$ in the latter is larger. As the axial angles are nearly identical, there must be a still greater difference in $\gamma - \alpha$. This conclusion is confirmed by the interference colours, the highest of which are, in usual thin sections, in the Orijärvi anthophyllite orange or red of the first order, while those in the Träskböle anthophyllite attain blue of the second order. In the former case we may assume that $\gamma - \alpha = 0.016$ to 0.018, in the latter $\gamma - \alpha$ must be 0.023 to 0.025.

In the dark-coloured anthophyllite mentioned above (cf. footnote 1) a zonal structure could be observed, the central zones of the prism being darkest. There is a considerable difference in birefringence between the zones: In the lightest border-zones $\gamma - \alpha$ is about 0.005 more than in the dark kernels.

C u m m i n g t o n i t e & a n t h o p h y l l i t e in homoaxial intergrowth (cf. page 183) seem more likely to occur in the plagioclase-bearing cordierite-rocks than in the true cordierite-anthophyllite-rocks. The cummingtonite is, however, very common in the rocks of the Orijärvi mine, especially in the varieties rich in quartz. In numerous slides made of such rocks the amphibole showed characteristics which resemble those described in the contact-facies of the Träskböle cordierite-anthophyllite-rock: The monoclinic modification forms lamellae parallel to (010) which are bounded at each side by the rhombic amphibole. The former is usually twinned on (100), and its birefringence is, without exception, higher than that of the rhombic lamellae. The quantitative proportion between both modifications is quite variable: either the one or the other is prevalent. Sometimes only narrow laths of anthophyllite occur at the borders of the prisms.

In the Orijärvi mine tremolite is also found in abundance (the tremolite-skarn). The following characteristics are diagnostic for the cummingtonite: (1) Its higher refringence, easily determinable according to the immersion method. (2) Its positive character (the tremolite is negative). (3) A homoaxial intergrowth with anthophyl-

[1] From a glacial boulder found near Lake Osmajärvi in Pojo. This boulder consists of cordierite-anthophyllite-rock and contains also biotite, dark green chlorite, quartz and sulphide minerals, chiefly chalcopyrite. It has probably been transported from the Orijärvi ore field.

lite. (4) The occurrence of acicular or almost fibrous prisms as fan-like aggregates (the tremolite forms thicker prisms and does not show any radial structure). Characters (3) and (4) do not occur in the cummingtonite of the cummingtonite-amphibolites.

The b i o t i t e is invariably rather pale in colour, showing $\mathfrak{c}$ = pale yellowish brown $< \mathfrak{a} = \mathfrak{b}$ = yellowish brown. It is nearly uniaxial. Pleochroic halos round minute crystals of zircon are common. In many cases I observed that the axial angle is larger in these halos than elsewhere, up to 20°. Pleochroism is noticeable in sections || (001) also. The axial colours are: $\mathfrak{c}$ = pale brown, no darker than the main part, $< \mathfrak{b}$ = brown $< \mathfrak{c}$ = orange brown. Biotite is always xenoblastic towards the anthophyllite, while it has basal planes when limiting cordierite. As to its prismatic zone, its crystalloblastic relation to the cordierite is not quite clear: In most cases both are equally xenomorphic, but sometimes scales with hexagonal though slightly rounded outlines are enclosed in the cordierite.

Z i r c o n is a regular accessory occurring as minute rounded crystals enclosed in the biotite. It shows the high interference colours characteristic of the unaltered type of this mineral.

The g a h n i t e, associated with sulphide minerals, is a common accessory, occurring mostly as minute green octahedra, but sometimes as irregular grains. It could be identified by means of its high refringence, tested by the immersion method with methylene iodide saturated with sulphur. All samples examined in this way gave the result that $n > 1{,}784$, i. e. the index of refraction is higher than that of hercynite or pleonaste. In several cases the presence of zinc was also proved by a chemical test.

Among the other minerals observed in the cordierite-anthophyllite-rock, only a l m a n d i n e deserves special attention. This mineral occurs at several places as red-coloured rounded crystals measuring two or three cm in diameter. Such occurrences are found: on the western and eastern shore of Lake Määrijärvi and east of the Perheentupa farm on the shore of Lake Orijärvi. It may be noted that the rock from one locality only has been examined microscopically, and it is possible that in other cases plagioclase may also be present, and the rocks should properly be termed gneisses. The almandine is always accompanied by quartz and biotite.

Occasionally almandine entirely replaces the typical constituents and the rock grades into almandine-biotite-rock containing quartz, just as in the occurrence near Träskböle. Such is the case on the cape named Granatinokka (=»Garnet-cape») at the northeastern shore of Määrijärvi. The almandine occurs here as red-coloured euhedral crystals, from 1 to 4 cm in diameter, embedded in a mass of biotite and quartz. The crystals usually present a combination of (110) and (211).

F. J. Wiik (20) quotes an analysis of »garnet from Orijärvi» which is probably from this locality; analyst W. Ungern:

SiO_2	36.73
Al_2O_3	16.20
FeO	40.13
CaO	4.00
MgO	2.88
	99.94

Garnet has not been found in the Orijärvi mine.

As appears from the chemical formulas, the same compounds from which cordierite and anthophyllite are formed, may also give garnet and quartz:

$$4RSiO_3 + R_2Al_4Si_5O_{18} = 2R_3Al_2Si_3O_{12} + 3SiO_2.$$

In the anthophyllite Mg can be replaced by Fe in all proportions, while in the cordierite only limited amounts of Fe take the place of Mg. Analyses of almandine garnets, on the other hand, show invariably only low percentages of magnesia. Thus the rock will contain garnet and quartz, if the Fe: Mg ratio exceeds a certain limit. In the opposite case cordierite and anthophyllite are constant.

The chemical composition of the cordierite-anthophyllite-rock.

On the basis of the microscopical examination we are able to draw some conclusions as to the total composition of the cordierite-anthophyllite-rocks from the Orijärvi area. These rocks are especially characterized by the absence of any minerals containing sodium or calcium. Consequently the rocks must be very poor in these compounds. Sometimes biotite is also absent or it is only present in small amounts. Then the rock must be poor in potash, while such varieties which contain abundant biotite must have considerable percentages of K_2O. The proportions of alumina, iron oxides and magnesia vary between the limits fixed by the percentages of these oxides in the cordierite and in the anthophyllite.

In most of the outcrops cordierite is in excess of all the other minerals. Thus it is evident that the rock must be rich in alumina. But usually when there is an abundance of cordierite, it is accompanied by abundant quartz, while the amount of biotite is small. The following proportions seem probable, e. g. for certain specimens from the mine.

Cordierite	50 %
Quartz	25 »
Anthophyllite	20 »
Biotite	5 »

The chemical composition of this mineral combination can be calculated as quoted below (I), using the analyses of the minerals from Träskböle and the analysis of the biotite from El Capitan:

The mineral composition of the extremely quartzose variety is, according to a rough estimate under the microscope:

Quartz	75 %
Cordierite	15 »
Anthophyllite	10 »

The chemical composition corresponding to these proportions is quoted under II.

Under III the calculated composition of a specimen rich in anthophyllite is given, assuming the proportions of the minerals to be:

Cordierite	20 %
Biotite	20 »
Anthophyllite	60 »

The minerals are present approximately in these proportions in a specimen from the outcrop north of the mining field.

	I	II	III
SiO_2	60.6 %	87.4 %	47.2 %
Al_2O_3	19.7 »	5.6 »	14.6 »
Fe_2O_3	0.5 »	—	1.2 »
FeO	8.6 »	3.3 »	18.0 »
MnO	0.2 »	—	0.4 »
MgO	8.6 »	3.1 »	13.8 »
CaO	0.2 »	0.1 »	0.5 »
Na_2O	0.1 »	0.1 »	0.4 »
K_2O	0.4 »	—	1.9 »
TiO_2	0.2 »	0.1 »	0.6 »
H_2O	0.9 »	0.3 »	1.4 »
	100.0 %	100.0 %	100.0 %

Cordierite-anthophyllite-gneiss.

Rocks containing considerable amounts of plagioclase, besides cordierite and anthophyllite, occur in the Orijärvi aureole on a larger scale than the rocks described above. They form the main part of the area between the large amphibolite sill north of Lake Orijärvi and the lake in question, and also are frequently met with on the islands of this lake. On the opposite side of the granite-batholith a rock of similar composition is exposed on the island of Kurksaari

Fig. 40. Cordierite-anthophyllite-gneiss. Tarklahti. Orijärvi.

in Lake Määrijärvi, on the western shore of this lake and in many other localities. Probably more of it exists in the bed of the lake.

This rock offers a peculiar appearance which seems characteristic of the plagioclase-bearing varieties: The cordierite forms rounded ellipsoidal crystals, protruding from the weathered rock-surface, often somewhat flattened in the direction of the strike. [1] The size of these apparently porphyroblastic individuals is variable, and

1 At the mapping, the knotty-looking porphyroblastic cordierite-rocks were provisionally called »nodular stones», while the cordierite-anthophyllite-rock which contains radiating, star-like aggregates of amphibole, was termed »starstone».

so is the proportion of the porphyroblasts and the gneissose ground-mass. A few examples may be described more in detail.

Cordierite-anthophyllite-gneiss from Tarklahti.

On a low rock in the Tarklahti bay, at the northwestern end of Lake Orijärvi, the cordierite-anthophyllite-gneiss is well exposed. The best outcrop (fig. 40) is, however, only visible at low water, which here occurs in the autumn. The ellipsoidal porphyroblasts are comparatively small here, most of them measuring approximately 10× 15×20 mm. The porphyroblasts are unevenly distributed, as is visible in the photograph. Such a lack of homogeneity is common to all these rocks of the Orijärvi region, but here it is less pronounced than usual, so that this rock could be analyzed chemically. The analysis, made by the writer, gave the following results:

Table XXXIII.

		Mol. prop.	Mol. %	Norm		Mode	
SiO_2	57.65	.961	63.3	Q	17.16	Plagioclase $Ab_{80}An_{20}$	25.1
Al_2O_3	16.84	.163	10.9	Or	14.46	Biotite	24.9
Fe_2O_3	0.85	.005		Ab	19.39	Quartz	18.8
FeO	10.33	.143	10.1	An	6.39	Anthophyllite, Cummingtonite	16.9
MgO	5.30	.133	8.8	Cor	8.06	Cordierite	12.8
CaO	1.28	.023	1.5		Σ sal 65.46	Ilmenite	2.0
Na_2O	2.34	.037	2.4	Hy $MgSiO_3$	13.30		99.7
K_2O	2.36	.026	1.7	Hy $FeSiO_3$	15.58		
TiO_2	1.60	.020	1.3	Il	3.04		
H_2O	1.08	—	—	Mt	1.16		
					Σ fem 33.08		
					98.44		
	99.63		100.0				

Osann's system:	s	A	C	F	n	a	c	f	k	T
	64.6	4.1	1.5.	18.9	5.9	3.5	1	15.5	1.39	5.3

The mode was calculated from the analysis on the basis of the following statements concerning the mineral constituents: The percentage of ilmenite was estimated at 2.0 %. This mineral occurs as tabular, slightly rounded crystals, enclosed in all the other minerals. All the potash was assumed to be present in the biotite, which was supposed to have the composition of the biotite from El Capitan. The biotite occurs abundantly in the ground-mass. It is brown-coloured with frequent pleochroic halos round minute crystals of zircon. All the soda was reckoned as being present in the plagioclase. This mineral forms the greatest part of the ground-mass, in which it occurs as polygonal grains averaging 0.25 mm in diameter. The extinction angles are in all sections almost exactly 0°. Therefore the twinning lamellae (of the albite type) are rarely noticeable. An inverse zonal structure is visible in certain sections. The parallel extinction ranges this plagioclase with the oligoclase of the composition $Ab_{80}An_{20}$. Its refringence is in accordance with this conclusion.

After the subtraction of the above compounds the following figures remain:

SiO_2	32.60	%
Al_2O_3	5.73	»
FeO	5.46	»
MgO	3.01	»
CaO	0.22	»
TiO_2	0.25	»
H_2O	0.43	»
	47.70	%

This remainder comprises the amphiboles, the cordierite and the quartz. An exact calculation of these constituents is impossible, as the percentage of alumina contained in the amphiboles is not known. The figures quoted under the mode were obtained on the assumption that the cordierite has the same composition as the Träskböle cordierite and that the amphiboles contain 9.4 % Al_2O_3.

The mode thus calculated agrees with the megascopical and microscopical observation. Small quantities of pyrite and chalcopyrite are also present. The cordierite contains abundant inclusions of quartz and is intergrown with the amphiboles.

The cummingtonite & anthophyllite occur in much the same way as in the contact-variety of the Träskböle rock (p. 183). Here also the minerals have the plane 100 as a composition face, and the monoclinic amphibole usually forms the central part being, moreover, frequently twinned on 100. The rhombic amphibole which forms the outer lamellae is here in excess of the cummingtonite. Both are so identical in refringence that a needle composed of the two mineral species looks, when seen with one nicol, like an individual crystal, even when the microscope is adjusted for observing the Becke line. Both minerals show a feeble brownish colour and a pleochroism which is only just noticeable: $\mathfrak{a} < \mathfrak{c}$. In the anthophyllite the optical arrangement is: a = $\mathfrak{a}$; b = $\mathfrak{b}$; c = $\mathfrak{c}$. In the cummingtonite the arrangement is the same, except that c : $\mathfrak{c}$ = about 20°. The birefringence is higher in the cummingtonite, i. e. $\gamma - \alpha = 0.025$ approximately, while in the anthophyllite $\gamma - \alpha = 0.016 - 0.018$ only. Thus the difference in the birefringence seems to be greater, though in both modifications the birefringence is lower than in the Träskböle amphiboles. The optical character is positive. In the rhombic form 2 V is probably between 80° and 85°. I found no lamellae of the monoclinic form broad enough to allow of observation in convergent light.

As calculated from the rock analysis, the amphiboles contain 1.4 % CaO, 10.9 % MgO and 28.6 % FeO. Thus the analysis affords an evidence that we have here ferro-magnesium amphiboles, and the almost identical refringence makes it very probable that the rhombic and the monoclinic amphiboles are heteromorphous modifications of one and the same substance.

The mineralogical and chemical composition of the Tarklahti rock is analogous to the hornfels of Goldschmidt's class 4: plagioclase-hypersthene-cordierite-hornfels. An analysis of such a hornfels from Berget in the Christiania region is quoted under I for comparison [1]. Under II we quote Hackman's analysis of the »hypersthene-cordierite-hornfels» from Umptek, Kola.[2] III represents the Tarklahti rock.

Table XXXIV.

	I.	II.	III.
SiO_2	58.28 %	58.66 %	57.65 %
Al_2O_3	17.98	18.86	16.84
Fe_2O_3	2.42	6.62	0.85
FeO	6.52	5.10	10.33
MnO	0.17	trace	n. d.
MgO	4.88	5.10	5.30
CaO	2.01	0.68	1.28
Na_2O	1.39	2.81	2.34
K_2O	4.29	2.93	2.36
TiO_2	0.21	—	1.60
P_2O_5	0.07	—	—
H_2O	2.19	0.63	1.08
	100.41	101.39	99.63

[1] V. M. Goldschmidt, »Die Kontaktmetamorphose im Kristianiagebiet» p. 162.

[2] W. Ramsay, »Das Nephelinsyenitgebiet der Halbinsel Kola», I, *Fennia* **11**, N:o 2, p. 51, 1894.

If similar composition is regarded as a sufficient proof of similar origin, the Tarklahti rock must doubtless be ranged with rocks of a sedimentary origin. But there are certain matters to complicate the problem, as will be shown later on.

The porphyroblastic cordierite-anthophyllite-gneiss passes by gradual transition into an anthophyllite-bearing plagioclase-gneiss devoid of cordierite (fig. 41). This rock is composed of oligoclase, quartz, biotite and anthophyllite & cummingtonite, besides ilmen-

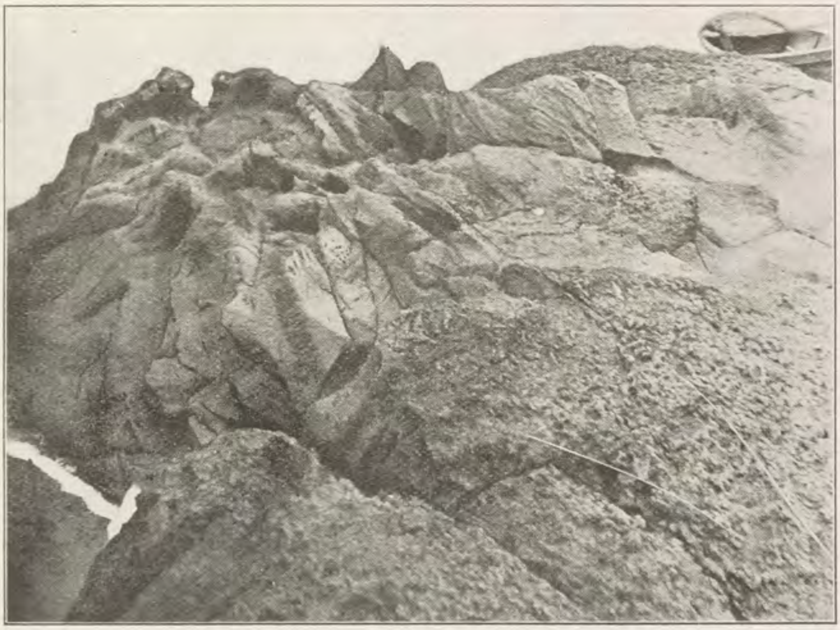

Fig. 49. Gradual transition of cordierite-anthophyllite-gneiss into plagioclase-anthophyllite-gneiss.

ite, pyrite, pyrrhotite and chalcopyrite as accessories. Thus the composition of this rock is probably much the same as that of many leptites, except that ferrous oxide and magnesia are more abundant. As seen in the illustration, the transition of this rock to cordierite-anthophyllite-gneiss takes place along quite irregular lines and is not that of various intercalated layers.

Cordierite-anthophyllite-gneiss near Perheentupa.

On the northern shore of Lake Orijärvi, near the bathing-house (finnish »sauna») of the Perheentupa farm, there is a beautiful outcrop where a number of rocks characteristic of this area can be studied in a small space (fig. 42). The rock is very typical (fig. 43), the cordierite-crystals having approximately the size of hen's eggs.

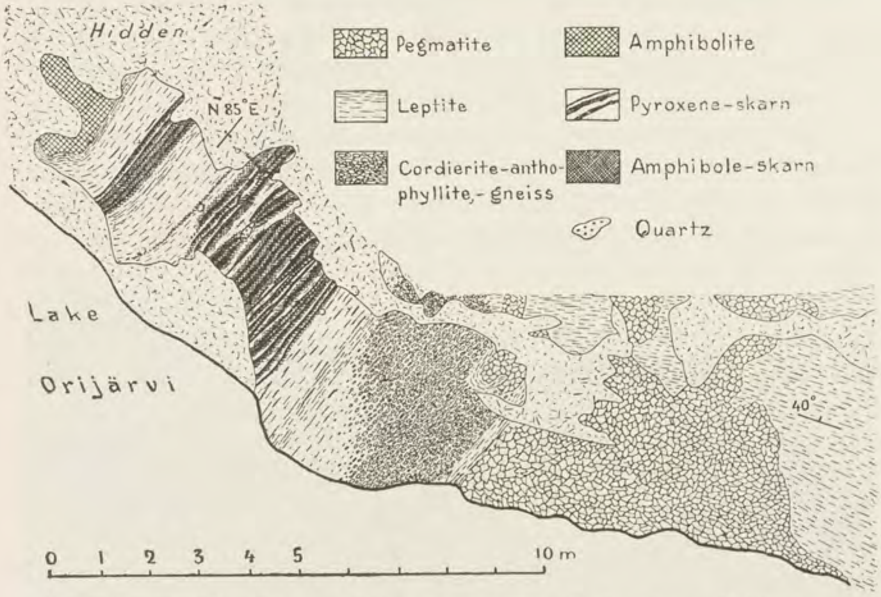

Fig. 42. Sketch-map of the outcrop near Perheentupa, Orijärvi.

Fig. 43. Cordierite-anthophyllite-gneiss near Perheentupa. Orijärvi. $^1/_5$ nat. size.

Quartz, anthophyllite and biotite are intergrown in the cordierite nodules which often show very irregular forms but nevertheless consist of individual crystals.

In fig. 42 the contacts of this rock are also shown. Towards the leptite, which is a fine-grained plagioclase-leptite of the usual type, poor in biotite, the transition is gradual: the porphyroblasts diminish and finally disappear. It may be seen that the boundary is not parallel to the strike of the leptite and the neighbouring skarn layers, but oblique to it and independent of the stratification. At the other side

Fig. 44. Cordierite-anthophyllite-gneiss, containing sharp-edged fragments of leptite-like rock. The cordierite crystals have rounded contours. Kurksaari, Määrijärvi, Kisko. $^1/_{15}$ nat size.

the cordierite-anthophyllite-gneiss is cut by a red granite-pegmatite. As is usual in such contacts, the cordierite has disappeared near the boundary-line and been converted to a gneissose rock rich in dark mica. Undoubtedly the cordierite-rock existed at the time of the intrusion of the pegmatite. Instead of producing similar contact-phenomena, its effect was to destroy the earlier contact-minerals near the contact and to convert the rock into a mica-schistose gneiss.

Cordierite-anthophyllite-gneiss on Kurksaari.

The little rocky island of Kurksaari in the northern part of Lake Määrijärvi is one of the finest outcrops of the cordierite-bearing rocks in the Orijärvi area. On the southern abrupt wall the rock is well

Fig. 45. Cordierite-anthophyllite-gneiss, Kurksaari. $^1/_9$ nat. size.

Fig. 46. Rounded crystals of cordierite from Kurksaari.

exposed, and the large crystals of cordierite, protruding from the weathered surface, are likely to attract ones attention already at a distance. These rounded crystals have some resemblance to pebbles, and the relief of the rock, on the whole, is not unlike that of certain conglomerates. Tigerstedt actually believed the Kurksaari rock to be a metamorphosed volcanic breccia. As he did not examine it microscopically, this mistake is not surprising, for the aspect of the cordierite is similar to that of a grey, aphanitic leptite, and the rather indistinct cleavage can hardly be detected if it is not looked for. Moreover, this rock also contains fragment-like inclusions, consisting of a fine-grained leptitic rock. The origin of these fragments must still remain unexplained, but it is possible that they in fact are relics of a primary agglomeratic structure.

As usual in the »nodular stones», the quantitative proportions between the porphyroblasts and the ground-mass are very variable. In the eastern part of the island the crystals are sparingly scattered (fig. 44). Leptitic fragments, on the other hand, are here common, as is visible in the photograph. Going to the west along the shore, the porphyroblasts become more numerous (fig. 45), and at the western point of the island the large crystals occupy more than a half of the whole rock.

Some crystals, loosened from the rock-surface, were photographed (fig. 46) in order to show their form and size. There are two different types: the narrow and long crystals and the thick and more rounded individual nodules. The optical investigation proved that the crystals are elongated parallel to the crystallographical axis c. In a slide cut at right angles to this direction, the crystal was found to be twinned repeatedly with 110 as twinning plane. Sometimes 110 is also the composition face, and even polysynthetic twinning-lamellae parallel to this plane were observed. But more usually the individual portions limit each other along irregular surfaces. One of the three individual systems forms the main part of the whole, the two other systems appearing as smaller scattered fields.

The ground-mass of this rock is always distinctly schistose. The large crystals also are sometimes arranged along the strike (fig. 45), but more often they have grown in all possible directions without any regularity, and frequently two crystals cross each other.

Microscopically, the porphyroblasts are seen to be stained with inclusions of quartz, ilmenite, monoclinic and rhombic amphibole, apatite, magnetite, pyrite and chalcopyrite.

The inclusions of q u a r t z show rounded contours (pl. V, fig. 2) resembling the forms of corroded quartz in igneous rocks.

Where the quartz-grains predominate, they show a well developed pavement structure with polygonal form of the grains. Though the individuals of quartz are quite irregular, they are distinctly arranged in rows along the direction of the foliation.

The ilmenite occurs as tabular crystals. A crystal taken at random measured 0.02 × 0.06 mm. The crystals are arranged in rows along the strike, and their flattening is parallel to this direction.

The prisms of apatite are smaller than any other inclusions; an average crystal measured 0.005 × 0.02 mm. They are arranged like the crystals of ilmenite.

The amphibole occurs as long needles, a usual size being 0.03 × 1.0 mm. They, too, are arranged mostly in the direction of the foliation, but some needles have different positions. In the needles a rhombic and a monoclinic amphibole are intergrown as in the rock from Tarklahti. Here also the composition face is (100), and the outer parts consist of anthophyllite, while there is, in the middle of the crystal, one or several lamellae of the monoclinic mineral (pl. V, fig. 1 and 2). It can be taken for granted that this amphibole is cummingtonite.

An approximate estimate under the microscope gave as a result that the inclusions fill up about half of the volume of the crystal, and that quartz alone occupies more than a quarter. The proportions are, however very variable, even in a single crystal. No zonality in the distribution of the inclusions can be inferred, except as regards the amphibole, which is more abundant in the outer parts than in the centre of the crystals.

The crystallographical arrangement of the porphyroblasts is independent of the foliation indicated by the arrangement of the inclusions.

A specimen of the ground-mass of the cordierite-anthophyllite-gneiss, collected from the middle part of the southern shore of the island of Kurksaari, is composed of anthophyllite, biotite, quartz, plagioclase, ilmenite, apatite, and cordierite. The last-named is present only as a few large xenoblasts, but in slides from some other specimens it was more abundant and even in excess of all other constituents.

The anthophyllite intergrown with cummingtonite is long-prismatic and occurs as single crystals or as fan-like bunches. It is the most idioblastic of all the constituents.

The biotite is present approximately to the same extent as the anthophyllite. It is of a rather light brown colour and shows numerous pleochroic halos round minute inclusions which probably consist of zircon.

Plagioclase forms, with the quartz, a hornfels with typical pavement structure, the average diameter of the grains varying from about 0.1 to 0.3 mm. Twinning lamellae are very rarely present. The extinction angle in a section $\perp$ (001) and (010) was 8.5°. $\gamma_1 > \omega$; $\varepsilon > \alpha_1$. From these data a composition $Ab_{73}An_{27}$ results.

Quartz, in excess of the plagioclase, forms part of the hornfelsmass.

Ilmenite and apatite occur as inclusions, which are, in form and arrangement, identical with those found in the large porphyroblasts of cordierite.

The fragments included in this rock deserve special attention. Their forms are irregular and sharp-edged (see fig. 44). They are grey or greyish white in colour and in their general appearance resemble a quartzite.

Under the microscope this rock was found to be composed of quartz, plagioclase, apatite, biotite, ilmenite and pyrite. The structure is granoblastic, the polygonal individuals measuring from 0.01 to 0.08 mm in diameter. Larger lenticular grains of quartz are embedded in this ground-mass, being at least 10 times as large in diameter as the hornfels grains.

A distinct parallel structure is observable, due to the arrangement of the biotite and the apatite and the quartz.

The most striking microscopical feature of this rock is the abundance of somewhat rounded minute prisms of apatite. A qualitative test proved the presence of much phosphoric pentoxide. One of the smallest of the prisms measured 0.003 × 0.005 mm and one of the largest was 0.02 × 0.07 mm. They are equally distributed and penetrate all the minerals of the hornfels mass, but they are not found in the central parts of the larger quartz-grains. A geometrical determination by the Rosiwal method, made with a high power objective, gave 14 vol. % apatite, or about 16 percent of weight. Two separate fragments were examined and found to be nearly identical.

In the fine-grained hornfels mass some individuals are biaxial with a large negative axial angle. The refringence as compared with quartz is: $\varepsilon > \gamma_1$; $\omega > \alpha_1$; $\gamma_1 > \omega$. In a few grains, feldspar cleavages are visible, but no twinning lamellae. The extinction angle in a section $\perp$ (001) and (010) was + 8°, in another section + 10°. According to these results the mineral is plagioclase of the composition Ab_{72} An_{28}. — Prisms of apatite are more frequent in the plagioclase than in the quartz.

Biotite as thin scales is present in small amounts.

Microcline being absent, the rock must be poor in potash. Magnesia also must be present only in very slight amounts, while iron oxides, entering into the ore-minerals, are more important, and alumina, lime, soda and phosphoric acid, with much silica, are the chief compounds.

As has already been pointed out, the most probable hypothesis concerning the origin of these fragments is that they are relics of fragments of an originally clastic (or pyroclastic) rock, and it seems that the phosphorus is also a primary compound. This opinion is corroborated by the frequent occurrence of more distinctly blastoclastic rocks in this vicinity, along the shores of Lake Määrijärvi. At times such rocks contain almandine, cordierite and cummingtonite. One of of these occurrences was described on page 157.

At the boundaries between the apatite-leptite and the cordierite-anthophyllite-gneiss very interesting contact-phenomena were observed. At such points where the apatite-leptite is bordered by the feldspar-bearing ground-mass of the cordierite-anthophyllite-gneiss, the contact-line is sharp. But where a large crystal of cordierite limits the fine-grained rock, there has the cordierite grown two or three mm into the leptite (pl. IV, fig. 2). The minute prisms of apatite and the large quartz grains have been enclosed in the cordierite, but all plagioclase grains and the smaller quartz grains of the hornfels mass have been replaced by the cordierite. The original boundary-line between the fragment and its country-rock is quite sharp, as visible in pl. V, fig. 1.

On the southern shore of Kurksaari there are some band-shaped portions in which the rock has developed as »star-stone», with no plagioclase. The anthophyllite occurs as radial aggregates (»stars») in a matrix which consists chiefly of cordierite.

The cordierite-anthophyllite-gneiss south-east of Koski, Tenala.

At the western end of the granite mass north of Skogböle, Tenala, there are a few exposures of a rock, which in its petrographical character and geological mode of occurrence resembles the cordierite--anthophyllite-gneiss of the Orijärvi aureole.

The oligoclase-granite has developed an endogeneous contact-zone, 200 or 500 m broad. Going outwards from the inner granite area one first observes a gradual transition into a porphyritic marginal facies. The ground-mass becomes finer, and the colour darkens from more abundant biotite, and finally the larger grains of quartz disappear. This fine-grained grey contact-facies contains numerous sharp-edged fragments of a leptitic gneiss which is here, as at Orijärvi, immediately adjacent to the granite.

The cordierite-anthophyllite-gneiss is exposed some 50 m from the contact; the outcrops are arranged in a belt which follows the direction of the granite contact for half a kilometer. The rock shows all the characteristics of the Orijärvi »nodular stone», as for instance in being non-homogeneous and frequently grading into cordierite-biotite-gneiss. Crystals of cordierite up to 10 cm long were found. The following constituents were observed under the microscope: cordierite, anthophyllite, quartz, biotite, andesine, ilmenite and pyrite. Megascopically almandine was often seen, and, north and south, the rock fades away into almandine-bearing amphibole-gneiss. Pyrite is present in abundance as small grains and stringes, but no other ore minerals were observed.

Quartz-cordierite-rock.

This rock occurs in the vicinity of the Orijärvi mine south of the great amphibolite-sill. It is a variety of what has been termed »hard quartzose rock» (»hårdt kvartsigt berg», Tigerstedt) which also embraces the cordierite-anthophyllite-rocks rich in quartz.

The largest body of the quartz-cordierite-rock is exposed in the hills situated about 200 m east of the mine, immediately north of the ore-mill. Megascopically this rock resembles a micaschistose gneiss, being rather coarsely crystalline and rich in biotite, with a distinct foliation. A microscopical examination of several specimens proved the rock to be devoid of feldspar.

The constituent minerals are quartz, cordierite, biotite and muscovite, and chlorite resulting from the alteration of the biotite. Apatite and zircon are found as very small inclusions in the other minerals. Galena and gahnite were frequently observed.

Among the main constituents, quartz is considerably in excess of the others, while cordierite and biotite are present in approximately equal amounts.

The quartz, as polygonal grains, forms a relatively coarse-grained hornfels mass, the individuals sometimes measuring as much as 0.5 mm in diameter. In cordierite and biotite it forms rounded inclusions.

The cordierite builds up large xenoblasts and is in part altered to muscovite and a chloritic substance seemingly isotropic, owing to aggregate polarisation.

The biotite occurs as scales which are stained with enclosed grains of quartz. It shows the axial colours: $\mathfrak{a}$ = pale brown $<$ $\mathfrak{b}$ = $\mathfrak{c}$ = brownish green. Brown biotite, however, also occurs in certain slices. The biotite is almost filled with pleochroic halos surrounding the minute prismatic inclusions of zircon, but is not observed around the apatite.

The gahnite is found as octahedra and shows, in thin sections, a very pale green colour. Its refringence was found to be higher than 1,784. This fact proves that this mineral must be a zinc-spinel (cf. p. 194).

Cordierite-gneiss.

The cordierite-bearing rocks already described show frequent transition into varieties composed of cordierite, plagioclase, quartz and mica. Such cordierite-gneisses are, as small lenticular bodies, distributed over the whole aureole. Especially they are widely spread in that part of the contact-belt which lies at the northern coast of Lake Orijärvi, east of the mine. They are there associated with the cordierite-anthophyllite-gneisses. In their general appearance these two rocks are very similar: the cordierite occurs as characteristic nodules, varying from 2 × 3 to 4 × 6 cm in size.

A good outcrop is found in an abrupt rock-wall, a few meters in height, near the farm of Orijärvi, southwest of the buildings. This rock has a ground-mass which resembles a mica-schist, in which numerous ovoidal individuals of cordierite occur, roughly 3 × 4 cm in size. These rounded crystals are of a greyish brown colour and show a peculiar resinous lustre. The lens is three or four meters thick and bounded by cordierite-anthophyllite-rock and quartz-cordierite-rock.

Under the microscope the ground-mass was found to be composed of quartz, biotite, muscovite, plagioclase and apatite.

Plagioclase, forming part of the granoblastic ground-mass, rarely shows any twinning when examined between crossed nicols. Nevertheless the twinning exists, but is not visible owing to the fact that the extinction angles are in most cases nearly at 45°. When a selenite-plate was inserted, a few lamellae could be seen in most grains. The maximum extinction angle found in sections $\perp$ (010) was 48°, which corresponds to the mixture $Ab_{25}An_{75}$ or bytownite. Compared with quartz, its strong refringence is very striking.

The porphyroblastic individuals of cordierite are quite unaltered. The megascopical brownish tint is owing to the fact that the yellow colour, which usually appears in the pleochroic halos only, is here almost universally spread. Its refringence, compared with quartz, is $\varepsilon > \gamma_1$; $\omega = \gamma_1$. Rounded grains of quartz and bytownite, and scales of muscovite and biotite, are enclosed in the crystals.

I determined geometrically, in numerous specimens, the quantitative proportion between the porphyroblasts and the ground-mass, and subsequently, under the microscope, the mineralogical composition of both. The result was, in percent of weight:

Table XXXV.

		Porphyroblasts	Ground-mass	Total
Porphyroblasts 60 %	Cordierite	67 %	— %	27 %
	Quartz	11	53	36
Ground-mass 40 %	Bytownite	9	18	14
	Biotite	12	27	21
	Muscovite	1	2	2
		100	100	100

In calculating the composition of the rock, Bonsdorff's analysis (p. 190) was used for the cordierite. For the biotite, we again use the analysis of this mineral from El Capitan (see page 220). The calculation leads to the figures quoted under I (table XXXVI).

Table XXXVI.

	I.	II	III
	%	%	%
SiO_2	64.9	58.83	55.90
Al_2O_3	18.4	17.54	19.94
Fe_2O_3	1.2	0.00	6.61
FeO	4.5	8.42	0.43
MnO	—	0.09	—
MgO	4.8	3.40	2.09
CaO	2.3	2.24	0.51
Na_2O	0.3	1.35	0.32
K_2O	2.2	4.35	1.33
TiO_2	0.2	0.59	—
S	—	—	1.16
SO_3	—	—	0.35
P_2O_5	—	0.46	—
H_2O	1.2	2.59	10.55
	100.0	99.85	99.39

The composition thus calculated is, as also the constituent minerals, in accordance with the hornfels of Goldschmidt's class 3, or plagioclase-cordierite-hornfels. For comparison we quote an analysis (II) of a hornfels of this class from Kolaas in the Christiania region.[1] Nearly identical analyses may be found among those of nonmetamorphosed clays. As an example, we quote an analysis (III) of Cambrian clay from Kiviniemi in eastern Finland.[2] A very close similarity in the composition of the three rocks may be noted. If only the chemical composition of the cordierite-gneiss is considered, it must undoubtedly be classed with the aluminous hornfelses. But when we remember its irregular occurrence in this area where pneumatolytic metamorphism has certainly played an important part, its genesis seems doubtful. A fuller discussion of this question will be taken up later.

Specimens of the cordierite-gneiss from other localities showed considerable variance in composition, appearing especially in the composition of the plagioclase which in some cases was found to be as albitic as $Ab_{90}An_{10}$.

The andalusite-bearing quartz-mica-rock.

The rocks of the northwestern part of the Orijärvi aureole are very difficult to describe in words, owing to their singular heterogeneous character. As a rule, they are brecciated: The rock has been broken up into pieces, re-cemented either with the same minerals as those composing the rock itself, or with quartz only, or with a mass consisting of much mica mixed with quartz. Often there are no sharp limits between the fragments and the cement. The rock presents the aspect of a schlieric and contorted mixture of irregular masses of various composition which are often elongated along the strike. Sometimes the homogeneous portions are one or two meters thick; more often the non-homogeneity can be traced even in thin sections under the microscope. Andalusite, mica and a few other minerals may occur as large crystals, but there is a granoblastic ground-mass, composed of quartz, or quartz and plagioclase, which was always found to be decimillimeter-grained. Thus the megascopic appearance of this rock, in a hand-specimen, is that of a fine-grained

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[1] V. M. Goldschmidt, »Die Kontaktmetamorphose im Kristianiagebiet», p. 156.

[2] B. Frosterus, »Det finska lermaterialet som geologisk bildning och teknisk produkt», *Geol. Komm. Geotekniska meddelanden* n:o 6, p. 68, 1909.

gneiss or mica-schist. In many parts of the area the schistosity is pronounced, but in some portions hardly noticeable (see fig. 52).

In parts of the most northwestern corner of the granite area, the marginal variety of the granite has also been thus brecciated. The porphyritic nodules of quartz have remained unchanged, allowing the rock to be identified, but the ground-mass has been converted into a gneiss, rich in biotite, and the »cement» between the fragmentary bodies is just as variegated as elsewhere in the andalusite-bearing contact-rock.

The brecciated rock seems to have been originally identical with the leptites in the environs, and it passes laterally into them, the fragmentary gneissose portions becoming larger and more homogeneous. These leptitic gneisses are composed of quartz, plagioclase and mica, either biotite or sericite or both.

Portions composed of only quartz and mica are very common. The mica is either only sericite or sericite and biotite. Such a quartz-sericite-rock occurs on a larger scale than elsewhere round the most northern point of the granite-mass. The rock is of a pale green tint, owing to the colour of the sericite, and brecciated, with a cement mainly of quartz. Pure quartz-veins along the strike are common.

At the Iilijärvi mine, light contorted bands of the quartz-sericite-rock and darker ones which contain biotite and often also plagioclase alternate in the most complicated manner, and the whole is cut across by small veinlets or intermingled with irregular bodies of sulphide ores and quartz.

Andalusite was sometimes found under the microscope as minute crystals in specimens in which it was not visible to the naked eye. Most of the andalusite however, occurs as large crystals which are very frequent in certain spots, while the main part of the rock is devoid of this mineral (fig. 47). The spots rich in andalusite usually present a lenticular shape and are, at most, two meters thick. The rock-mass in which the crystals are embedded, is either plagioclase-bearing or composed of quartz and mica. Sometimes the andalusite is enclosed in pure quartz.

Cordierite occurs in much the same manner as the andalusite. Often it is found as an accessory, in small quantities. But in places it is very abundant. Within the andalusite-bearing area there are spots of a few square meters, where cordierite, developed as large nodules, gives the rock the appearance of the porphyroblastic cordierite-gneiss.

Sericite is almost universally present in the andalusite-bearing rock. It is worthy of notice that in this rock amphiboles were never observed. Another negative characteristic is the absence of potash feldspar. This feature, common to all contact-metamorphic rocks of the Orijärvi aureole, is especially striking here, as the rocks are so rich in micas, i. e. contain much potash.

The minerals of the andalusite-bearing rock.

The plagioclase is often the most abundant constituent of the brecciated rock, though it cannot be identified with the naked eye. The polygonal individual grains are usually devoid of any

Fig. 47. Crystals of andalusite in a fine-grained gneissic rock. Near Grönqvist, Kisko.

twinning-lamellae. An average diameter of 0.3 mm was observed in several slides.

The plagioclase varies in composition from $Ab_{85}An_{15}$ to $Ab_{55}An_{45}$. Many gradations between these limits were observed.

The sericite occurs as thin scales, usually about 0.5 mm at their largest diameter. It is either white (Iilijärvi) or pale green (near Grönqvist). The optical properties of this mica are identical with those of muscovite, but the axial angle is small. I measured in several slides 2 E with a Klein's lens and obtained values from 20° to 30°. At the Iilijärvi mine a light mica occurs as larger scaly crystals (up to 3 mm broad) in which 2 E was found to be 41°.

The b i o t i t e is of the common pale-brown type, almost uniaxial. It is always xenoblastic towards the sericite. Both kinds of mica are equally idioblastic towards andalusite and cordierite. Minute rounded crystals of z i r c o n are common inclusions in the biotite.

The a n d a l u s i t e is euhedral only when it is surrounded by quartz or by a hornfels mass rich in plagioclase, as in the case illustrated in fig. 54. But when it occurs in rocks rich in mica, it shows irregular rounded forms. Well-shaped crystals of the former kind have been found in many places. Faces (110) and (001) are dominant, but in certain crystals, several domes and pyramids were also observed. The crystal faces, however, are somewhat rounded and uneven. Cleavage parallel to (110) is distinct. The angle 110 : $1\bar{1}0$ was measured in cleavage-splinters of a crystal which was taken from the outcrop illustrated by fig. 47. The results varied from 89° 19′ to 89° 25′. — The largest crystals which I observed were about 10 cm long.

The colour is pale pink; a = $\mathfrak{a}$; b = $\mathfrak{b}$; c = $\mathfrak{c}$; the character negative. The indices of refraction were determined in two prisms, one of which had its refracting edge ∥ c and the middle plane ∥ (010), while the other prism was cut so that the refracting edge was ∥ b and one side ∥ (001). The results were:

	Prism I	Prism II	Average
α_{Na}	1.6348		1.6348
β_{Na}	1.6402	1.6405	1.6403
γ_{Na}		1.6443	1.6443

The acute axial angle was calculated from the above figures:

$$2\ V_{Na} = 80°\ 34'.$$

The axial angle in methylene iodide was also measured directly in a plate cut ∥ (001), resulting in

$$2\,I = 77°\ 10'.$$

From this figure we obtain:

$$2\ V = 82°\ 50'.$$

The andalusite contains many inclusions. Crystals of biotite and muscovite or sericite are the most common (pl. IV, fig. 3). They present the form of euhedral six-sided scales. In the andalusite from the Iilijärvi mine large scales of biotite are specially abundant. Quartz also is found, as rounded grains. Moreover, several titanium-bearing minerals were observed. T i t a n i t e in the form of globular crystal-groups occurs commonly. In a specimen from south of Lake Iilijärvi, a black ore mineral occurs as tabular crystals. It is probably i l m e n i t e. In the crystals from the Iilijärvi mine, r u t i l e was found as minute acicular simple crystals and larger crystals, up to 0.02 mm in diameter, which are twinned on (101) and have a form identical with that illustrated in Rosenbusch's »Physiographie» (I, 2, fig. 22, p. 48, 1905).

The c o r d i e r i t e is xenoblastic and often greatly altered to muscovite or chlorite.

In the andalusite-bearing rock near Grönqvist there are microscopical crystals of a mineral which I could not identify. They show rhombic sections in which the acute edges are truncated by pinacoidal planes. The mineral is feebly pleochroic with dark reddish brown and orange brown tinges, and shows an extremely high refringence and low birefringence.

The composition of the andalusite-bearing rocks.

If the bulk composition of the andalusite-bearing rocks could be determined, they would probably be found to be somewhat poorer in (Fe,Mg)O and richer in SiO_2, Al_2O_3 and K_2O than the average leptites. It might be a composition which is common in sedimentary rocks. In this case, however, the peculiar characters of the rock forbid any supposition of an original sedimentary composition.

It may be noted, that no granitic or pegmatitic intrusions were found within the area of the andalusite-bearing rock. The brecciated character of the rock must be of a later date than the consolidation of the oligoclase-granite, as part of the granite has also been brecciated. If there were any intrusions from the oligoclase-granite in this area, they must have been changed like their country-rocks, and thus have been entirely obliterated. Nor have any intercalations or sills of amphibolite, prior to the metamorphism, been preserved well enough to be recognized with certainty (cf. below). A few amphibolite dikes (cf. page 115) intersect the brecciated rock and show no trace of the brecciation: They must be of a later date than that metamorphism which gave rise to the singular character of the andalusite-bearing rock.

Dark bands in the andalusite-bearing rock.

In the andalusite-bearing rock some dark-coloured bands occur, showing indistinct border-lines towards the country-rock. The occurrence of such bands in an area where the nondisturbed rocks are frequently associated with amphibolites, naturally suggests the idea that these bands may represent an altered modification of the amphibolite. Therefore a specimen of this rock, collected about 150 m south of the Iilijärvi mine, was subjected to a quantitative examination. The analysis was made by the writer (Table XXXVII).

Table XXXVII.

		Mol.prop.	Mol. %	Norm	
SiO_2	51.50	0.858	60.0	Q	11.16 %
Al_2O_3	19.67	.193	13.5	Or	32.80
Fe_2O_3	0.34	.002		Ab	1.05
FeO	10.62	.147	10.5	An	3.61
MnO	0.12	.001		Cor	12.14
MgO	5.94	.144	10.1	Σ sal	60.70
CaO	0.67	.013	0.9	Hy $MgSiO_3$	14.40
Na_2O	0.18	.003	0.2	Hy $FeSiO_3$	17.95
K_2O	5.54	.059	4.1	Fe_3O_4	0.46
TiO_2	0.70	.009	0.7	$FeTiO_3$	1.37
S	0.11	.003	—	FeS_2	0.21
H_2O	4.36	(.242)	—	Σ fem	34.39
	99.75		100.0		95.09

Osann's system:	S	A	C	F	n	a	c	f	k	T
	60.7	4.3	0.9	20.6	0.5	3	1	16	1.27	8.3

The actual mineral constituents are cordierite, biotite, muscovite and chlorite, the two last-mentioned being products of the alteration of the two former, and quartz, apatite, pyrite, arsenopyrite and rutile. A rough estimate gave the result that biotite + chlorite, and cordierite + muscovite are present in equal amounts, while the quartz is less in quantity.

The cordierite occurs as large xenoblasts in which scales of biotite and grains of quartz are enclosed. Biotite is of the usual brown type.

The chlorite presents pseudomorphs after the biotite, with preserved crystallographic arrangement. It shows low blue interference colours and a negative character (penninite).

Colourless needles from 0.001 to 0.008 mm thick, occur frequently in the chlorite. They show parallel extinction with positive elongation, and a birefringence of 0.100 or more. These properties prove this mineral to be rutile. Characteristically the needles do not occur in the unaltered biotite which probably contains the corresponding quantity of titanium dioxide in its molecules.

When comparing this analysis with those of the amphibolites we see that there is no great difference in the percentages of SiO_2 or (Fe,Mg)O, while the present rock is much poorer in CaO and Na_2O, but richer in K_2O and Al_2O_3. The potash might be supposed to have been added by secondary processes whereby the muscovite was formed at the expense of the cordierite, but it is fairly evident that this alteration has been accompanied by the alteration of biotite into chlorite:

$$\underset{\text{Biotite}}{K_4H_2Mg_6Al_6(SiO_4)_9} + \underset{\text{cordierite}}{2\,Mg_2Al_4Si_5O_{18}} + \underset{\text{water}}{11\,H_2O} = \underset{\text{muscovite}}{4\,H_2KAl_4(SiO_4)_3} + \underset{\text{penninite}}{H_{16}Mg_{10}Al_2Si_6O_{33}} + \underset{\text{quartz}}{SiO_2}$$

Thus the high percentage of potash must be no less primary than the biotite.

The results of the analysis are in accordance with the supposition that this rock had originally the composition of an amphibolite which had altered through a pneumatolytic process whereby much potash was carried in and the plagioclase and amphibole were replaced by cordierite and biotite. Regarding the geological occurrence of this rock, it is far more improbable that it has any unchanged composition of a sedimentary rock.

The plagioclase-biotite-gneiss.

Plagioclase-gneiss at the granite contact near the Orijärvi mine.

A narrow belt of plagioclase-gneiss occurs between the oligoclase-granite and the cordierite-bearing rocks near the Orijärvi mine. It shows the same mineralogical and structural characteristics as the ground-mass of many examples of the cordierite-gneiss, but it contains no cordierite. In a specimen taken from an outcrop immediately south of the Lustikulla shaft, the plagioclase was found to be oligoclase.

Approaching the contact from the granite area, the quartz-porphyritic contact-facies of the granite becomes gradually distinctly foliated. No sharp limit between the granite and the gneiss could be detected; one might suppose that this plagioclase-gneiss itself is simply a foliated modification of the endogeneous contact-rock, but any definite proofs of such a hypothesis cannot be found. This plagioclase-gneiss, on the other hand, passes gradually into cordierite-gneiss or into cordierite-anthophyllite-gneiss.

Blastoporphyritic plagioclase-gneiss southeast of Iilijärvi.

Among the very non-homogeneous rock-masses occurring within the Orijärvi aureole, the blastoporphyritic plagioclase-gneiss is the most homogeneous one and best deserving to be called a »rock». Striking from east to west it forms part of the belt of blastoporphyritic leptites described above (page 139). Within the contact-metamorphic aureole this rock shows, on the weathered surface, nearly the same knotty appearance as elsewhere, but in fresh surfaces it resembles a highly metamorphic biotite-gneiss more than anything else. In the field, frequent quartz-veins and, in places, thin veinlets of chalcopyrite etc., remind us of a pneumatolytic influence. Sometimes the rock shows nearly the same brecciated appearance as the neighbouring andalusite-bearing rocks.

A specimen of this rock was analyzed by the writer (table XXXVIII).

Table XXXVIII.

		Mol.prop.	Mol. %	Norm		Mode	
SiO_2	72.06	1.201	76.2	Qu	41.70	Quartz	46.8
Al_2O_3	12.51	.123	7.8	Or	12.79	Plagioclase	18.8
Fe_2O_3	0.72	.004		Ab	13.62	Biotite	34.4
FeO	3.93	.054	4.1	An	8.34		100.0
MnO	0.19	.003		Cor	4.49		
MgO	4.14	.103	6.6	Σ sal	80.94		
CaO	1.70	.030	1.9	Hy $FeSiO_3$	6.47		
Na_2O	1.59	.026	1.7	Hy $MgSiO_3$	10.30		
K_2O	2.20	.023	1.5	Il	0.61		
TiO_2	0.34	.004	0.2	Mt	0.93		
H_2O	1.03	—	—	Σ fem	18.31		
	100.41		100.0		99.25		

(Almerose).

Osann's system:	s	A	C	F	n	a	c	f	k	T
	76.7	3.2	4.6	10.7	11.3	3.5	5	11.5	1.96	2.7

The mode was calculated from the analysis. Small amounts of a p a t i t e and l e u c o x e n e were not considered. If all Na_2O would enter into the p l a g i o c l a s e, this would have the composition $Ab_{63}An_{37}$. This mineral shows, under the microscope, no twinning, but very distinct cleavage cracks. Extinction angles of about 20° are most common. In several sections ⊥ (010) and (001) an extinction angle of 23° was measured. The indices of refraction are higher than those of quartz. Thus the optical properties indicate a mixture of about $Ab_{57}An_{43}$. The excessive soda (0.37 %) as well as all other residual bases were assumed to be present in the biotite. For this mineral, silica and water were allotted according to the formula: $m(H,K)_2Al_2(SiO_4)_2+n(Mg,Fe)_2SiO_4$. Thus the following composition results (I).

	I	II	III
SiO_2	40.9 %	36.02 %	33.95 %
Al_2O	21.7 »	18.81 »	17.69 »
Fe_2O_3	2.1 »	5.60 »	n. d.
FeO	11.4 »	14.75 »	21.94 »
MnO	0.5 »	0.80 »	trace
MgO	12.1 »	9.82 »	7.98 »
CaO	—	0.65 »	1.10 »
Na_2O	1.1 »	0.38 »	1.00 »
K_2O	6.4 »	9.32 »	8.39 »
TiO_2	1.0 »	1.13 »	3.40 »
H_2O	2.8 »	2.57 »	3.46 »
		F 0.26 »	ZrO_2etc. 0.98 »
	100.0 %	100.11 %	99.89 %

Considering the large percentage of biotite and the simple mineral composition of the rock, these figures should be fairly accurate. The agreement with the typical granite-biotite (II) from Yosemite valley, Cal.,[1] is complete in everything except that the amount of potash is considerably lower in the present example. The difference is greater than any probable error in my determination of this compound. On the other hand, an analysis of brown biotite from hornfels in the Christiania region, made by P. Jannasch[2] (III), is more in disagreement.

This biotite shows comparatively pale colours: $\mathfrak{a}$ = almost colourless, brownish, $\mathfrak{c}$ and $\mathfrak{b}$ = greyish brown. Pleochroic halos are numerous, due to minute grains of zircon.

The ground-mass has a well developed honey-comb structure, and the grains are constantly between 0.1 and 0.2 mm in diameter.

[1] H. W. Turner, *A. J. S.* VII, p. 294, 1899. Quoted in »Quantitative Classification», table XIV, a.

[2] H. O. Lang, *Nyt Mag. f. Naturv.* **30**, p. 318, 1886, quoted by V. M. Goldschmidt, »Die Kontaktmetamorphose im Kristianiagebiet», p. 405.

Larger subparallel scales of biotite are idioblastic towards the other minerals. The rounded nodules of quartz, 1 to 8 mm in diameter, are also granulated, the grain being, however, somewhat coarser than that of the ground-mass.

The composition of this rock differs markedly from that of any ordinary igneous rock. The atomic proportions, calculated according to Becke (cf. page 151) are:

Si	70.5
U	24.3
L	5.2

These figures range this rock with rocks of sedimentary origin to which it doubtless does not belong, as the geological relations afford sufficient evidence that it must be a metamorphosed eruptive. Unhappily its composition cannot be compared with that of its less changed form outside the aureole, as the blastoporphyritic rocks are there very variable in composition (cf. page 139). But it seems probable that ferrous iron and magnesia have been added at the expense of alkalis. In other words, biotite has replaced all the potash feldspar and probably part of albite.

The cummingtonite-amphibolite.

The boundary-zone of the amphibolite sill north of Orijärvi.

The amphibolite north of Lake Orijärvi shows, along its southern boundary, a pale-coloured zone of variable breadth, usually about 0.5 m only. This boundary-facies of amphibolite is composed of the same minerals as the main rock-mass, but the largest part of the amphibole consists of c u m m i n g t o n i t e, which occurs as idioblastic prisms of about 0.2 × 1 mm. Its intergrowth with the hornblende and its optical properties are the same as those of the cummingtonite found in the inner part of the sill (page 112). A n t h o p h y l l i t e in a homoaxial intergrowth with the cummingtonite was also observed, though only in one among numerous slices. This intergrowth which shows quite the same characteristics as that which occurs so commonly in the cordierite- and anthophyllite-bearing rocks, seems to be very rare in the cummingtonite of the amphibolites.

I tried to separate the cummingtonite from a finely ground and washed rock powder by means of methylene iodide, but this attempt resulted in a complete failure: In a solution whose specific gravity was 3,146, the greater part of both amphiboles floated. When the liquid was diluted gradually, they sank contemporaneously. At 3,092 both had sunk, and the sample thus obtained contained about 30 % hornblende, i. e. approximately in the original proportion. Thus the cummingtonite and the hornblende are nearly identical in their specific gravity, and both are non-homogeneous. The amphibole thus separated was analyzed with the following result (I). The specimen had been taken from an outcrop a few meters west of the Julin shaft.

Table XXXIX.

	I.		II.	
	%	Mol.prop.	%	Mol.prop.
SiO_2	53.04 %	.886	49.58 %	.826
TiO_2	0.42	.005	0.56	.008
Al_2O_3	6.43	.063	8.10	.079
Fe_2O_3	1.24	.008	3.35	.021
FeO	15.47	.215	12.32	.171
MnO	0.26	.004	0.31	.004
MgO	18.46	.462	15.41	.385
CaO	3.08	.055	7.99	.143
Na_2O	n. d.	—	0.91	.015
K_2O	n. d.	—	0.11	.001
H_2O	n. d.	—	0.56	.031
	(98.40)		99.20	

Under II the analysis of the amphiboles from the inner mass is given for comparison. The percentages of lime and alumina are lower in the mineral now in question. From these results it might be concluded that the colourless amphibole contains a few percent alumina, but very little lime.

The plagioclase in this boundary-zone shows a marked inverse zonal structure, and its composition is variable between the same limits as that of the plagioclase in the main rock (page 112). The boundary type must be somewhat richer in magnesia and ferrous iron, poorer in lime.

Cummingtonite-amphibolite west of the Orijärvi batholith.

As has already been mentioned the most frequent occurrences of the cummingtonite-bearing rock are west of the granite-mass, in the Määrijärvi basin. From these rocks are intimately associated with and show gradual transition into those amphibolites in which all or nearly all the amphibole is green hornblende.

The typical cummingtonite-amphibolite, in which almost all amphibole is colourless, is chiefly composed of c u m m i n g t o n i t e and p l a g i o c l a s e. B i o t i t e often occurs in considerable amounts, and i l m e n i t e is a characteristic accessory. The texture shows no difference from that of the amphibolites. Blastoporphyritic and agglomeratic structures may also be observed, just as in most other amphibolites in this region.

The cummingtonite-amphibolites occur as sill- or dike-shaped masses in the cordierite-bearing rocks. A characteristic example of the latter kind may be found on the southern shore of the island of Kurksaari. A dike of pale greyish brown, even-grained rock, approximately one meter thick, intersects the porphyroblastic cordierite-anthophyllite-gneiss (cf. page 203). The latter has indistinct boundary-lines towards the cummingtonite-amphibolite, as though its minerals had grown to a certain distance from the contact into the dike-rock.

A specimen from this dike was analyzed by the writer (table XL).

Table XL.

		Mol.prop.	Mol. %	Norm		Mode	
SiO_2	53.40	0.890	56.5	Q	2.28	Plagioclase,	
Al_2O_3	16.33	.160	10.1	Ab	29.34	$Ab_{55}An_{45}$	48.9%
Fe_2O_3	0.78	.005		An	28.91	Cummington-	
FeO	9.72	.135	9.4	Σ sal	60.53	ite	47.9
MnO	0.23	.003		Di $CaSiO_3$	0.81	Ilmenite	3.0
MgO	7.46	.187	11.9	Di $MgSiO_3$	0.40	Hematite	0.2
CaO	6.16	.111	7.1	Di $FeSiO_3$	0.40		100.0
Na_2O	3.50	.056	3.6	Hy $MgSiO_3$	18.30		
K_2O	0.04	—	—	Hy $FeSiO_3$	14.65		
TiO_2	1.75	.022	1.4	Il	3.34		
H_2O	0.52	—	—	Mt	1.16		
				Σ fem	39.06		
					99.59		
	99.89		100.0				

A u v e r g n o s e, near H e s s o s e.

Osann's system:	s	A	C	F	n	a	c	f	k
	57.9	3.6	6.5	21.9	10.0	2	4	14	1.03

This rock shows, under the microscope, a very simple mineral composition: A mosaic of plagioclase is interlaced with colourless amphibole prisms and frequent tabular ore crystals. The plagioclase only rarely shows twinning lamellae of the albite-type. A marked inverse zonal structure is visible. An individual grain cut ⊥ (010) and (001) showed in the kernel an extinction angle of +20° and in the shell one of +29°. These values correspond with $Ab_{46}An_{54}$ and $Ab_{62}An_{38}$ respectively. The composition of the plagioclase being thus variable, its mean could not be determined exactly, but was roughly estimated at $Ab_{55}An_{45}$.

The cummingtonite is optically positive with a large axial angle. Its optical arrangement is the usual one: $a = \mathfrak{a}$; $b = \mathfrak{b}$; $c : \mathfrak{c} = 19°$ to 20°. At certain points there are minute spots of green-coloured amphibole. The cummingtonite was assumed to contain Fe_2O_3 and TiO_2 in the same proportion as was found in the cummingtonite from the Orijärvi mine (page 222). Further, 0.9 % Na_2O was assumed, in accordance with the analysis of the hornblende from the Orijärvi amphibolite. Thus the following composition results:

Table XLI.

		Mol. prop.
SiO_2	53.4 %	.890
TiO_2	0.4	.005
Al_2O_3	6.1	.060
Fe_2O_3	1.3	.008
FeO	17.4	.242
MnO	0.5	.007
MgO	15.6	.390
CaO	3.3	.059
Na_2O	0.9	.015
H_2O	1.1	.061
	100.0	

The agreement with analysis I page 222 is very close. There are two uncertain points in the above process of calculation: (1) The mean composition of the plagioclase could not be ascertained accurately; (2) the amount of Na_2O contained in the cummingtonite is unknown. The possible mistake in those rather arbitrary suppositions on which the calculation was based, might imply considerable errors in the above figures. The conclusion that this amphibole must be chiefly a ferro-magnesium amphibole is, however, beyond dispute.

The residual percentages of TiO_2 and Fe_2O_3 were supposed to enter into the ilmenite, for which an amount of FeO equivalent to TiO_2 had been allotted.

The cummingtonite-amphibolite from Kurksaari belongs to the Auvergnose subrang in the quantitative classification. One might suppose, at first sight, that the composition of this rock would be that of an ordinary igneous rock. A comparison with analyses quoted in Washington's tables, however, proves that rocks belonging to this or related subrangs which show such an excess of (Fe,Mg)O over the femic lime, are very rare (4 among 71 auvergnoses).

This fact, in connection with the occurrence of the cummingtonite-amphibolites only in the contact-aureole, and their frequent transition into ordinary hornblende-plagioclase-rocks, makes it probable that they have been derived from the amphibolites through secondary processes by which the amount of (Mg,Fe)O has increased at the expense of CaO. This conclusion is confirmed by the fact that the »cummingtonitization» is most complete at the boundaries of the amphibolites and going inwards gradually diminishes. The inner portions of the larger amphibolite bodies generally contain very little or no cummingtonite.

The skarn.

The tremolits-skarn.

Tremolite-skarn occurs in the Orijärvi region: (1) in the Vanha Pahalahti iron mine and (2) in the Orijärvi mine.

In the former locality a layer of tremolite-skarn is exposed in the wall of an old pit. The rock is composed of pale greenish brown tremolite occurring as long prisms in a matrix of chlorite and magnetite.

In the Orijärvi mine tremolite-skarn forms a layer which stretches along the amphibolite hanging wall. It is impregnated with sulphide minerals, and indeed the richest copper and zinc ores of the mine have been found in this »soft rock» (»blött berg»). The greatest part of the body of tremolite-skarn has now been mined out (cf. fig. 53 and 54). The layer is lenticular in form, attaining its greatest thickness at a depth of about 30 m. Below this level, it slowly tapers and ends at about 120 m, where the amphibolite wall curves round and assumes a southerly dip (cf. fig. 53).

This body of »soft rock» is very heterogeneous. Some parts are composed almost exclusively of tremolite in coarsely columnar masses. The individuals prisms are mostly about 5 cm long and 1 cm broad, but the coarseness as well as the habit and colour of the tremolite is exceedingly variable. More commonly, prisms of tremolite are embedded in a schistose mass composed of chlorite and biotite or talc.

The chlorite often is the main constituent, and tremolite is absent. Such a very soft rock, composed of chlorite and biotite, forms a large mass in the drift named »Holmens ort», at the 30 m level. In places the chlorite-schist contains octahedral crystals of magnetite, up to 2 cm in diameter. Such schistose rocks in which slender prisms of anthophyllite are embedded in a fine scaly mass consisting of chlorite and biotite are very common. Large lumps of yellowish brown cordierite (»hard falunite») also occur in this variety.

The chloritic rocks generally occur along sliding planes, called »sköl» by Swedish miners. Tigerstedt characterizes the body of tremolite-skarn simply as a »system of sköls».

Crystalline limestone occurs at several points within the tremolite-skarn in the eastern parts of the mine, usually a few meters from »the great sköl». At the surface limestone is exposed in the northern wall of the opening of Lindsay-grufvan. The limestone is rich in contact-minerals, such as different amphiboles, diopside and chondrodite (or serpentine formed through the alteration of the chondrodite) and ore minerals.

Diopside-skarn is also associated with the tremolite-skarn. I had no opportunity of seeing any occurrence of diopside-skarn in place, but there are facts to prove that it does not form any large coherent bodies. It usually accompanies the limestone.

I will not give any exhaustive description of the minerals found in the tremolite-skarn; all the species mentioned by former writers are named in the index of minerals, and references to the literature concerning them may be found in the bibliography. A few notes on the tremolite and the diopside, however, will be useful here.

The tremolite in most specimens is pale in colour showing a delicate brownish green tinge which is not likely to be confused with the clove-brown colour of the anthophyllite or cummingtonite. I determined by the immersion method two indices of refraction in a section of pale-green tremolite cut parallel to the plane of symmetry:

$$\alpha_{Na} = 1.601; \ \gamma_{Na} = 1.625.$$

The optical arrangement is: $a = \mathfrak{a}$; $b = \mathfrak{b}$; $c : \mathfrak{c} = 18^\circ$. The character is negative, the axial angle being not far from 90°.

Of the dark green Orijärvi tremolite two analyses (I and II) are available, made by students at the chemical laboratory of the University of Helsingfors (**20**, p. 92). Under III we quote an analysis made by Michaelson (**14**) of dark-green »hornblende» from Orijärvi, embedded in »talc-schist».

	I	II	III
SiO_2	56.92 %	56.44 %	55.01 %
Al_2O_3	5.10 »	8.63 »	1.69 »
Fe_2O_3	—	—	0.56 »
FeO	1.01 »	2.36 »	3.46 »
MnO	—	—	0.51 »
MgO	20.99 »	21.12 »	23.85 »
CaO	16.68 »	11.82 »	13.60 »
K_2O	—	—	0.38 »
Na_2O	—	—	0.48 »
Loss on ignition	—	—	1.02 »
	100.70 %	100.64 %	100.56 %
Sp.g.	2.91 »	—	3.03 »

It may be noted that analyses I and II which are quoted in most mineralogical text-books have been made by unskilled analysts and on material of an uncertain purity. Analysis III no doubt represents more exactly the composition of the Orijärvi tremolite.

This calcium-magnesium amphibole from Orijärvi has been termed partly tremolite, partly actinolite. The optical properties as well as the analyses prove, however, that only inconsiderable percentages of FeO are present. Therefore I have called the mineral which composes the main part of the skarn tremolite and not actinolite. It is to be noted that true actinolite also is found in the mine, being megascopically black and occurring as long prismatic crystals.

The occurrence of tremolite and cummingtonite in the same rock-mass, each showing its individual character, proves decisively that the amphiboles of the types $R_3Ca(SiO_3)_4$ and $RSiO_3$ are two different species which are miscible only in certain limited proportions.

The diopside also is of variable colour, sometimes almost black. There is probably much variation in the percentage of iron, though the two available analyses both happen to be made on almost pure diopside. Analysis I was made at the chemical laboratory of the University of Helsingfors **20**; analysis II, quoted by N. Nordenskiöld (**2** page 97), was made by H. Rose in 1820.

	I	II
SiO_2	53.45	54.64
Fe_2O_3	2.80	—
FeO	—	1.08
MnO	0.68	2.00
MgO	16.12	18.00
CaO	25.05	24.94
	98.10	100.66
Sp. gr.		3.195

Stress must be laid on the fact that the tremolite-skarn unlike the other skarn-rocks contains magnesia in considerable excess over

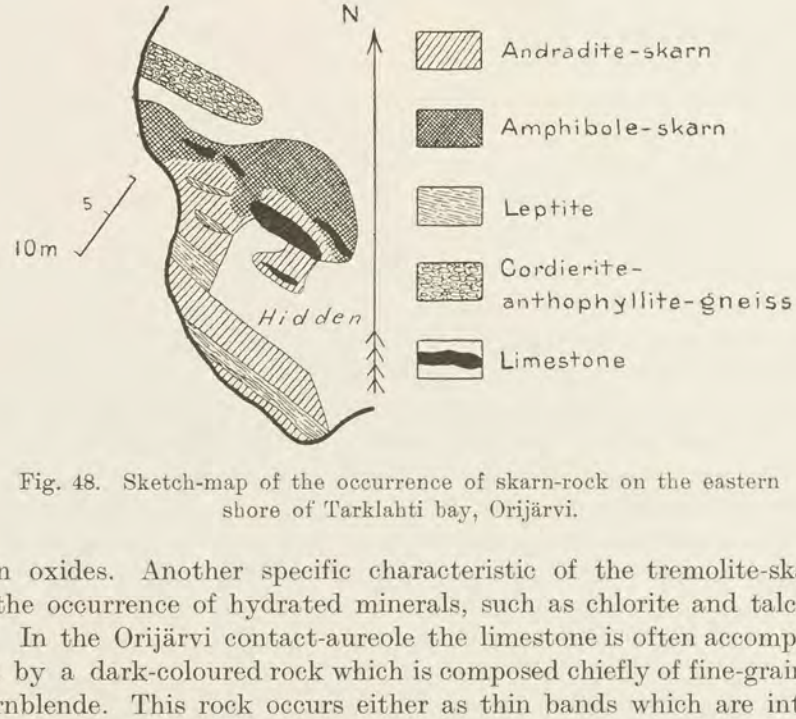

Fig. 48. Sketch-map of the occurrence of skarn-rock on the eastern shore of Tarklahti bay, Orijärvi.

iron oxides. Another specific characteristic of the tremolite-skarn is the occurrence of hydrated minerals, such as chlorite and talc.

The hornblende skarn.

In the Orijärvi contact-aureole the limestone is often accompanied by a dark-coloured rock which is composed chiefly of fine-grained hornblende. This rock occurs either as thin bands which are intercalated with bands of pyroxene-skarn and leptite (fig. 42, p. 202), or it forms irregular and more massive bodies (fig. 48). In several cases such rocks were found to be composed of hornblende, with small amounts of titanite, magnetite and quartz. In other occurrences diopsidic pyroxene is present as large xenoblasts in which the rounded hornblende grains are enclosed. The hornblende-rock near Tarklahti contains appreciable amounts of magnetite. Greater part of the iron ores which occur along the boundary of the granite, e. g. at Uusi Pahalahti, Haukia and Malmberg, are also associated with hornblende-skarn.

The hornblende was found to be very uniform in the different occurrences. Its optical arrangement is a = $\mathfrak{a}$; b = $\mathfrak{b}$; c : $\mathfrak{c}$ = 20°. The character is negative and the axial angle is probably 70° to 75° . Dispersion of axis B is visible: $v > \varrho$. The pleochroism is: $\mathfrak{a}$ = pale yellowish green < $\mathfrak{b}$ = olive green > $\mathfrak{c}$ = bluish green. The colours are much paler than those of the hornblendes in the pyroxene-amphibolites.

Sustschinsky (41, p. 203, footnote) gives the following analysis of bluish green hornblende from hornblende-skarn at the Haukia mine (analyst Hork):

SiO_2	44.09 %
$Al_2O_3 + Mn_3O_4$	14.60 »
Fe_2O_3	5.73 »
FeO	20.29 »
MgO	2.85 »
CaO	11.23 »
Alkalis	0.28 »
H_2O	0.74 »
	99.81 %

The hornblende-skarn differs from the amphibolites intercalated with or intersecting the limestone in so far as it does not contain any feldspar.

This hornblende-rock is, in all probability, a metasomatic skarn and has originated through complete replacement of the original carbonatic substance. It might be genetically analogous with certain amphibolites in Canada which are, according to Adams, [1] products of the action of granite magma on limestone. Here, however, the action can not have been due immediately to the magma, but must have been of a pneumatolytic nature.

The pyroxene-skarn.

There are intermediate rock types between the hornblende- and the pyroxene-skarn, and gradual transitions from the one to the other. Usually, however, the contacts are sharp, and the pyroxene-skarn is entirely free from amphiboles, but instead of this contains small amounts of andradite. The latter mineral was never found associated with the hornblende. Furthermore the rock may contain epidote, quartz and, occasionally, much calcite.

[1] »On the Origin of the Amphibolites of the Laurentian Area of Canada», *Journ. Geol.* XVII, p. 1, 1909.

The pyroxene is h e d e n b e r g i t e; its optical properties are the same as those of the pyroxene in the andradite-skarn (page 231), and on weathered surfaces this pyroxene assumes the colour of rust, while the diopside-skarn outside the aureole remains greenish grey.

The hedenbergite-skarn occurs as bands of variable breadth, — sometimes only a few millimeters thick, as seen in fig. 42, and sometimes up to 3 meters, e. g. in an outcrop between Perheentupa and Tarklahti. The amount of andradite increasing this rock grades into the andradite-skarn.

The andradite-skarn. The andradite-skarn occurs as bed-shaped masses. On a small island near Perheentupa it is intercalated with hornblende-skarn and amphibole-bearing leptite (fig. 50, p. 232), just as the pyroxene-skarn. East of Lake Orijärvi similar occurrences were observed at

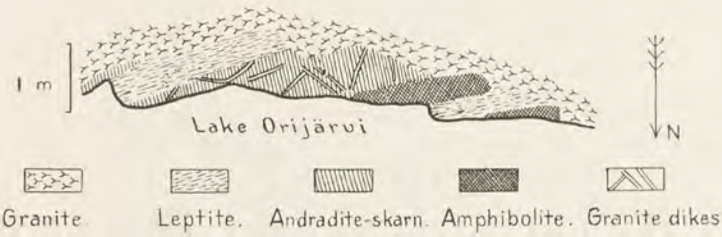

Fig. 49. Layers of andradite-skarn in contact with the oligoclase-granite. Near Niemi, southern shore of Lake Orijärvi.

several points, often accompanied by limestone. On the southern shore of Lake Orijärvi layers of andradite-skarn are found in immediate contact with the granite (fig. 49. This place is visible only at low water). In thicker layers, the andradite-skarn is exposed on the lake-shore east of Tarklahti bay (fig. 48).

Andradite-skarn also occurs near the western contact of the granite-mass, e. g. in the iron mine of Vanha Pahalahti. Near this old mine, on the shore of Määrijärvi, there is an amygdaloidal amphibolite exposed, showing a slaggy structure (like the one described on page 97), in which the original cavities had been filled up with calcite. Such calcitic amygdules have here been converted into andradite-skarn.

Dark green h e d e n b e r g i t e invariably accompanies the andradite, sometimes occurring in small amounts only, but more often in considerable quantities. M a g n e t i t e, q u a r t z and c a l c i t e are ordinary minor constituents. The structure is characterized by the absence of crystalline forms in any mineral (pl. IV, fig. 5).

The andradite forms rounded grains, often enclosed in the other minerals. The grains of hedenbergite are irregular but approximately equidimensional, while the three accessory constituents fill up the interstices between the others. The quartz often displays irregular undulatory extinction.

The andradite from the rock near Perheentupa was analyzed by the writer. The result was:

Table XLII.

	%	Mol. prop.	
SiO_2	37.13	0.601	0.606
TiO_2	0.44	.005	
Al_2O_3	7.27	.071	.195
Fe_2O_3	19.74	.124	
FeO	3.60	.050	.613
MnO	0.74	.010	
MgO	none	—	
CaO	31.06	.553	
H_2O	0.13	—	
	100.11		

$$RO : R_2O_3 : RO_2 = 3.144 : 1 : 3.108$$

The excess of Ro and RO_2 over the garnet ratio indicates that the sample contained some hedenbergite. These impurities, however, cannot affect the $Al_2O_3 : Fe_2O_3$ ratio, from which it may be calculated that this garnet contains 63.6 % of the andradite molecules. The refractive index determined in a prism, was found to be:

$$n_{Na} = 1.853.$$

The andradite is in all localities in the Orijärvi-field of a brownish red colour, and never presents any crystalline form.

The same prism contained also an individual grain of hedenbergite, in which two fortuitous indices of refraction could be determined:

$$\alpha_{1\ Na} = 1.717$$
$$\gamma_{1\ Na} = 1.739$$

As $\gamma_1 - \alpha_1$ (= 0.022) is here approximately the same as $\gamma - \alpha$ may be concluded to be from the interference colours, it is evident that the prism happened to be cut so that almost the highest and the lowest indices were obtained. A graphic interpolation from

Fig. 50. Andradite-skarn intercalated with hornblende-skarn (dark) and bounded by leptite (light). The layer of skarn is bent towards an interruption filled by quartz (white). A little island near Perheentupa, Orijärvi.

the data given by Wülfing [1] led to the conclusion that this pyroxene contains 80 to 83 % $CaFeSi_2O_6$. This result accords with the extinction angle $\mathfrak{c} : \mathfrak{c} = 47.5°$.

[1] »Beiträge zur Kenntnis der Pyroxenfamilie». Heidelberg, 1891, quoted in Rosenbusch's »Mikr. Physiogr.» I, 2, p. 202 and 203, 1905.

This hedenbergite shows a noticeable pleochroism: $\mathfrak{a} = \mathfrak{b} =$ pale bluish green; $\mathfrak{c} =$ yellowish green.

Quartz-veins across the skarn layers.

A peculiar phenomenon may often be seen in the thin layers of hornblende-, pyroxene- and andradite-skarn: the layers are interrupted by veins or lumps of quartz, and taper towards such interruptions. If the skarn is composed of different layers, these have been bent inward. Such a lump of quartz is visible in fig. 42. Fig. 50 illustrates a case where a series of skarn layers has been bent unsymmetrically. The intersecting quartz vein never continues any farther into the adjacent leptite, but where thin layers of skarn are intercalated with equally thin layers of leptite, it may happen that the leptite is also cut off (fig. 51).

The explanation of this phenomenon seems simply to be that the metasomatosis of the limestone into skarn has caused a contraction of the volume: the layers have been broken off and the opened spaces probably filled up with the solutions which circulated in the rock, and from them later on quartz has crystallized. The »granite dikes» shown in fig. 49 possibly have their origin due to the same cause. These dikes or veins are rather pegmatitic and rich in quartz.

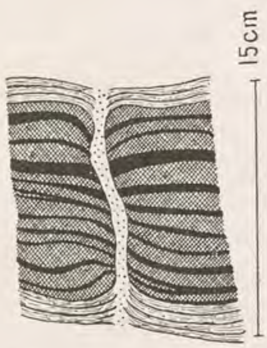

Fig. 51. A part of the layers of skarn illustrated in fig. 42, showing a cross-cutting quartz vein and bending of the layers.

The metasomatic nature of the skarn in the contact-aureole.

The different kinds of the skarn rocks show a mode of occurrence quite analogous to that of the limestone. Often pure limestone occurs as lenticular masses surrounded by the skarn (cf. fig. 48). Sometimes the whole of the layer consists of skarn, but in its continuation along the strike pure limestone may be met with. These facts make it probable that the skarn has originated through an alteration of the limestone; this alteration has most likely taken place in a metasomatic way, the mechanics of which can hardly be explained in detail. The chemical change has resulted in an addition of silica and iron oxides and, in the case of the tremolite-skarn, magnesia. The analysis of the andradite showed an appreciable percentage of alumina. It cannot be decided whether this compound had existed originally in the limestone or had been added with the other siliceous compounds.

We are led to the conclusion that these metasomatic skarn-rocks are of quite a different origin than the diopside-skarn which commonly occurs in the leptite area and is believed to have originated through mutual reactions between the limestone and the adjacent siliceous rocks.

The sulphide ores.

The Orijärvi mine. The Orijärvi mine was worked continually from 1757 to the late seventies of the 19:th century. The quantity of ore-bearing rock mined out during that time is estimated by Trüstedt (**36**) at 662,654 tons, from which 133,525 tons of smelting ore have been obtained. This has yielded 4,139 tons of copper in all, or 3.1 % of the smelted ore, and 0.62 % of the total quantity of mined rock. Besides copper ore the mine has given zinc ore and lead ore, but these were left unused, until 1869. The bulk of them is still to be found in the piles of waste rock near the mine. According to Trüstedt's estimate the quantities of metals contained in the piles are: 1,575 t. zinc, 450 t. lead and 900 kg silver.

An increasing diminution in the amount of minable ore finally necessitated the closing down of the mine. Several attempts were made to re-open it and to discover new deposits. For this purpose the ore field and the mines were explored, in 1889 and 1890, and a series of diamond drill borings was carried out. All this work was done by Tigerstedt (**25** and **26**). It was established that considerable quantities of ore still existed beneath the deepest drifts. Trüstedt estimated the amount of probable ore at 400,000 tons, from which 4,000 tons of copper, 1,300 tons of zinc, 350 tons of lead and 8 tons of silver may possibly be obtained.

Up to 1907 the Orijärvi mine belonged to the Fiskars estate, and had been worked by its owners. In that year the mine was purchased by the Finnish American Mining Company. It was now reopened and new mining machinery was installed. The main shaft (the Julin shaft) was sunk from about 100 m to 170 m[1] and some new drifts were run. An ore-mill and concentrating plant were erected. This enterprise, however, was not based on sound principles and ended in failure. At present the old mine is once more being filled with water.

The mine is situated at the southern boundary of the great amphibolite sill (see map II and fig. 52). The boundary of the oligo-clase-granite is situated about 180 m to the South. As the latter seems to dip about 45° to the North, while the amphibolite wall (»the great sköl») takes a less inclined position and at deeper levels turns round to assume a southerly dip, it is probable that the granite,

[1] According to private information. It is very regrettable, from a technical as well as from a geological point of view, that the Company did not leave any exact records of what was found in the new openings in the deepest part of the mine, wich are now filled with water.

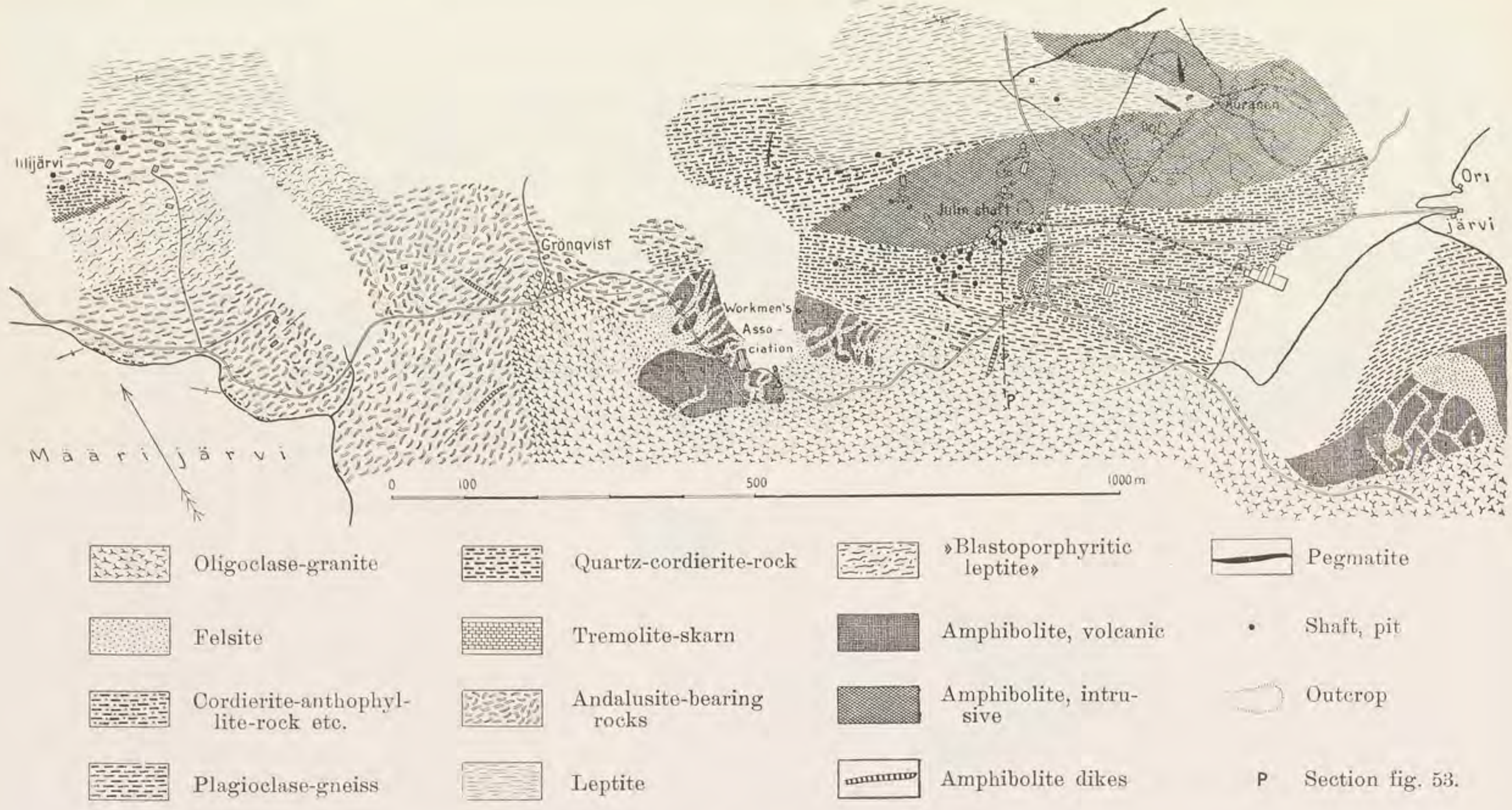

Fig. 52. Sketch-map of the Orijärvi mining-field. Scale 1: 10,000.

at some not very great depth below the mine cuts the amphibolite. This hypothesis is schematically illustrated by fig. 53.

Sulphide ores occur: (1) in the tremolite-skarn, — »the soft ore», and (2) in the cordierite-bearing rocks, — »the hard ore». (Fig. 53 and 54).

The greater part of the lenticular body of tremolite skarn has been ore-bearing. The sulphide-minerals found here are c h a l c o-

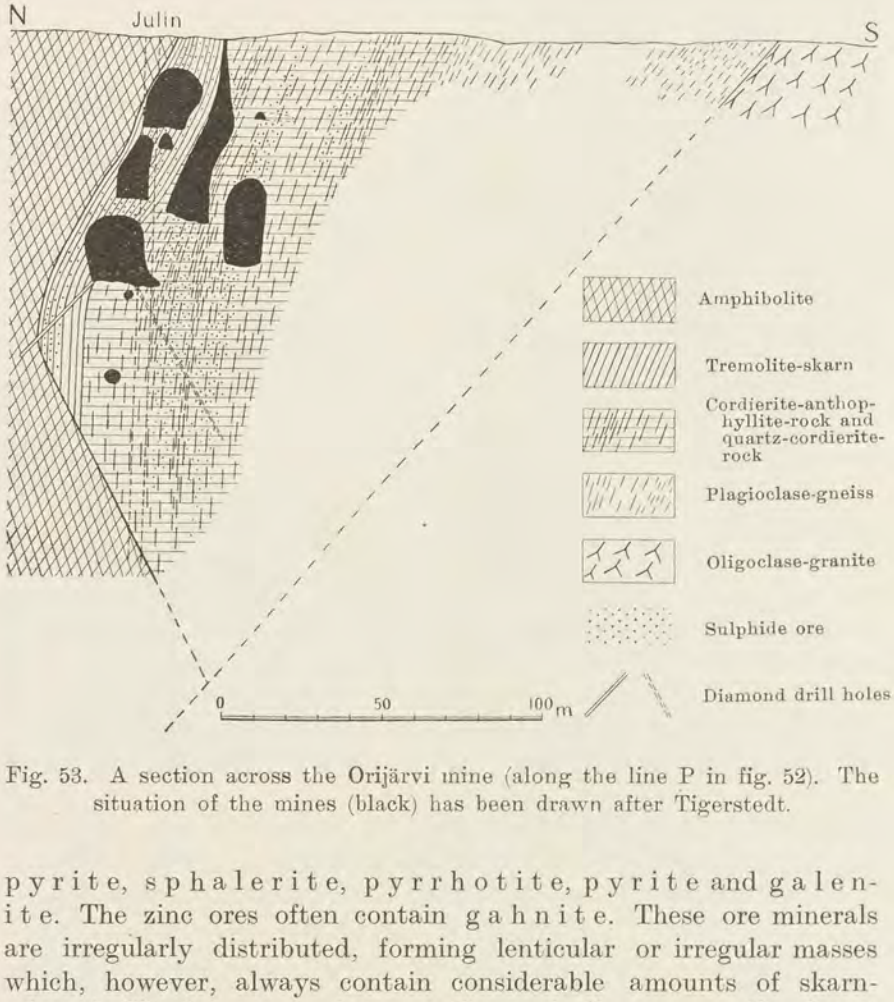

Fig. 53. A section across the Orijärvi mine (along the line P in fig. 52). The situation of the mines (black) has been drawn after Tigerstedt.

p y r i t e, s p h a l e r i t e, p y r r h o t i t e, p y r i t e and g a l e n i t e. The zinc ores often contain g a h n i t e. These ore minerals are irregularly distributed, forming lenticular or irregular masses which, however, always contain considerable amounts of skarn-minerals. The interspaces between the ore-bodies are usually almost free from sulphides or only impregnated with small ore particles which fill the interstices between the individual prisms of the amphibole or traverse the rock as narrow veinlets.

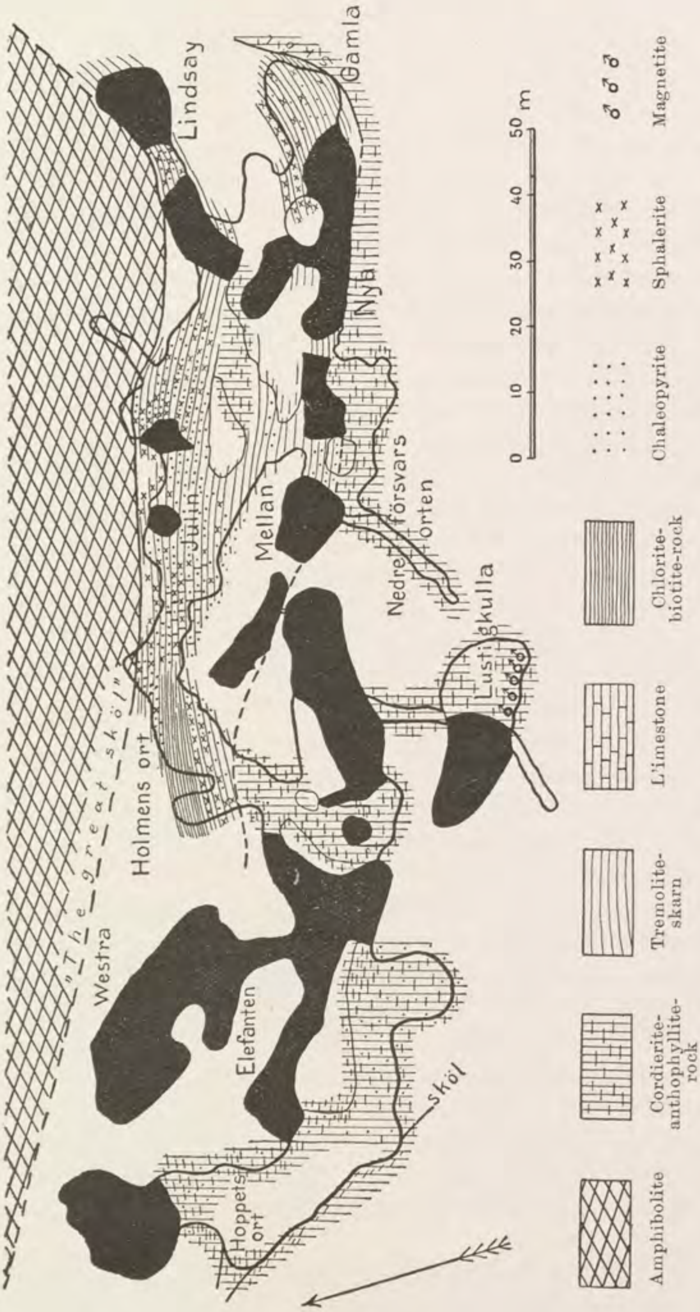

Fig. 54. Plan of the Orijärvi mine at the 30 m level. After Tigerstedt. The rocks are delineated mainly according to the observations of the writer.

The richest ores have been found close to the amphibolite-wall. So far as can be concluded, the occurrences of limestone have been situated in the midst of this zone. The limestone itself is, however, generally poor in sulphides, being only impregnated with small grains. Sphalerite and galenite more than the chalcopyrite seem to favour the limestone. The diopside is commonly associated with galenite.

The soft ores are mixed, but either chalcopyrite or sphalerite forms the main ingredient. The structures are exceedingly variable. Most varieties of zinc ore are coarsely crystalline. A common type is composed of sphalerite as large individual grains (up to 1 in cm diameter) whose interspaces are filled by fine-crystalline chalcopyrite and galenite. This zinc blende, like the greater part of the Orijärvi blende, is dark in colour and probably contains more than 10 % Fe.[1] Pale brown varieties, however, also occur.

Microscopical examination of the skarn-rock impregnated with sulphides affords convincing evidence of the epigenetic nature of the ore. Usually the ore-minerals have intruded between the individual tremolite prisms (pl. IV, fig 3). Very often the prisms have been broken up into pieces, which have been re-cemented with sphalerite, chalcopyrite etc. (pl. IV, fig. 4). In each case it is evident that the infiltration of the metal sulphides has not been due to any mechanical intrusion only, but that the silicates have thereby been corroded, as is clearly visible in the microphotographs. Consequently the genesis of the ores must have been due to a metasomatic replacement, not only of calcite but also of siliceous minerals, by the sulphides. The gahnite shows quite the same phenomena as the sulphides (pl. IV, fig. 4): corroded remnants of the amphibole have been enclosed in this zinc aluminate.

Though it is evident that siliceous minerals also are susceptible to metasomatic alteration, it is no less certain that the limestone presents a higher degree of susceptibility. Thin sections of limestone impregnated with abundant sulphides illustrate this relation in a striking manner: Accessories in the limestone, such as chondrodite, tremolite and diopside, have been enclosed in the sulphides retaining the same habit which they present when enclosed in the calcite. It seems probable that the greater part of the soft ore has originated through a replacement of the calcite. This is certainly the case with those portions of ore which are still visible in the floor of the »Holmens ort» drift (fig. 54).

The ore-bearing »hard quartzose rock» is, for the greatest part, cordierite-anthophyllite-rock containing abundant quartz. On a

[1] An analysis of blende from Orijärvi (**13**, p. 10) shows 10.31 % Fe.

smaller scale there are quartz-cordierite-rocks. Plagioclase rarely occurs and only as a minor constituent in the cordierite-bearing rocks, but occasional fine-grained portions are composed chiefly of plagioclase and quartz, showing the composition and structure characteristic of leptitic gneiss. They do not contain ore. Other layers are composed chiefly of amphiboles (anthophyllite & cummingtonite) besides chlorite or talc.

The main sulphide mineral of the hard ore is chalcopyrite, while sphalerite and galenite are here of less importance. Pyrite and pyrrhotite usually accompany the chalcopyrite.

The hard ore is simply a rock containing sulphide minerals as minor constituents. When very rich in quartz, this rock displays a well developed pavement structure, the quartz occurring in the form of polygonal grains. The cordierite is present as large xenoblasts in which numerous small rounded grains of quartz are enclosed, and the prisms of anthophyllite & cummingtonite traverse both quartz and cordierite. The chalcopyrite and the other sulphides form part of the granoblastic mass; the ore grains are of the same order of coarseness as the quartz grains and have similar polygonal shapes, only more irregular (pl. IV, fig. 6). This is the usual appearance of the impregnated rock. But when the ore minerals are abundant, they have separated as larger irregular stringes, or filled up cavities. In this mode of occurrencee the ore minerals show a markedly epigenetic character. This could not be said, if the rock impregnated only with minute grains were considered alone.

The sulphide bodies in the cordierite-bearing rocks are rarely more than a few centimeters in diameter. On the whole, the ore minerals are uniformly distributed, and the impregnated rock, considered as copper ore, is a low-grade one. There are three lenticular masses of such ore (fig. 53), separated from each other by rock-masses which contain only small amounts of sulphide minerals.

As Tigerstedt remarks, the axes of elongation of the lenticular ore-bearing masses incline towards the East, in accordance with the general direction of the folding axis in this region. Thus the largest ore deposits in the western part of the mine were situated near the surface, while those in the eastern portion were found at deeper levels. The curving of the amphibolite-wall, which implies the nether limit of the ore-bearing tremolite-skarn, also shows the same hitch in an easterly direction.

The order of crystallization of the sulphide minerals is not clear from a microscopical examination, though very often all of them occur in one and the same thin section. It seems as though they had crystallized contemporaneously. Megascopical examination of hand specimens and specially of mineral druses gave some further elucidation as to the order of crystallization and the mode of origin of the ores and the associated gangue minerals.

As already mentioned, the groups of large crystals of cordierite have orignated in drusy cavities which have later been filled with quartz and chalcopyrite, pyrrhotite, sphalerite, molybdenite etc. Anthophyllite sometimes also occurs in the same manner; in this case the terminal faces of its crystals, never observed when this mineral occurs as a constituent of the rock, have also developed. The sulphide minerals generally fill up the peripheral parts of the cavities. In other specimens the sulphides enclose crystals of quartz in which, however, chalcopyrite and other sulphide minerals have also been enclosed. It appears that the filling up of the cavities was generally begun by the crystallization of the different sulphide-minerals which all separated contemporaneously. At the same time crystals of quartz began to form, the crystallization continuing even after the separation of the sulphides.

Occasionally several other gangue minerals have crystallized together with and after the quartz, such as fluorite and dolomite. The crystals of these minerals have finally been covered by calcite. More often, however, only crystals of quartz protrude from the walls of the cavity, and the centre has remained open.

The Iilijärvi mine. With the exception of the Orijärvi mine, there is but one occurrence of sulphide minerals known within the Orijärvi aureole of any probable economic value. This is the Iilijärvi mine, situated west of the Orijärvi mine. There are three old pits once worked for copper but abandoned long ago until, in 1909, gold was found in the rock piles near the western pit by Mr. R. Franck. Since then some exploration work has been done. The ore minerals occur in the andalusite-bearing quartz-mica-rock (p. 212) and, in the southern pit, in almandine-bearing cordierite-cummingtonite-rock (p. 189).

The ores are of still more complicated composition than those at Orijärvi: Chalcopyrite, sphalerite, galenite, pyrite, arsenopyrite and pyrrhotite all occur in intimate association. The gangue consists of whitish translucent quartz with andalusite, sericite, biotite and cordierite (or brown-coloured products of its alteration, the so-called falunite). Gold is found as minute flakes in andalusite and quartz. Selenium-bearing lillianite ($Pb_3Bi_2S_6$) is associated with galenite. This mineral has been described by Borgström (38).

In other exposures of the andalusite-bearing rock no sulphides have been observed.

Chalcopyrite, sphalerite and galenite, besides gahnite, are widely spread in the various rocks of the aureole, but, so far as is known at present, only in small amounts. The cordierite- and anthophyllite-bearing rocks especially contain sulphides. On the island of Paavoholma in Orijärvi a pit has been made in the chalcopyrite-bearing rock. The amphibolite round the Workmen's Association house (p. 100), generally well preserved from any pneumatolytic action, has, however, in part been invaded by quartz-veins and become brecciated. Near the quartz-veins the rock (as well as the veins) is impregnated with pyrrhotite, pyrite and chalcopyrite. Southeast of Iilijärvi narrow veinlets of chalcopyrite occur in the leptitic gneiss (p. 219). The quartz-veins in several places contain small amounts of sulphides. Finally it may be mentioned that chalcopyrite and other sulphides have been found associated with magnetite, e. g. in the Malmberg mine. *Small occurrences of sulphides in the Orijärvi field.*

The oxide ore.

The occurrences of iron ores in the Orijärvi field and in the whole of the southwestern Finland have been surveyed magnetometrically. This exploration was carried out in common by several iron founderies, in the beginning of this century. Geologically they have not yet been studied in any detail.

Iron ores associated with limestone and skarn occur at several places close to the boundaries of the Orijärvi granite. They have been worked at Malmberg, Haukia and Uusi Pahalahti. Other occurrences have not been of any economic value. As the mines now are filled with water and the rocks in place usually not exposed, only the piles of rock near the openings can be studied. *The skarn ore.*

The Malmberg mine is the most extensive, the greatest pit being 57 m deep. The ore was detected here in 1670 and worked until 1866, when the mining ceased owing to outside circumstances, and not to exhaustion. Between 1854 and 1866 the average yearly production was 725 tons of ore (containing about 35 % iron). The nature of this occurrence is very difficult to explain. The rock surrounding the ore is a grey leptitic gneiss with no noticeable schistosity. Part of the magnetite occurs in a skarn-rock composed chiefly of hornblende, with smaller amounts of diopside and calcite. But the greater part of it seems to have been embedded immediately in the leptitic rock. This ore also contains much quartz. Sulphides, among which molybdenite may be mentioned, are also to be found.

The Haukia mine, worked from 1833 to 1863, yielded in all 2,268 tons of ore. The magnetite appears here in hornblende-skarn. Coarsely crystalline limestone occurs in the rock piles. It contains diopside, epidote and garnet, probably grossularite. Dikes of pegmatite intersect the ore-mass. Limestone is exposed some 30 m north of one of the pits.

The Uusi Pahalahti or Loviseberg mine consists of two pits, the greater of which is 34 m deep. They were worked from 1846 to 1863, the total production being 5,400 tons of ore. Here, too, the ore-bearing rock is hornblende-skarn which forms the main part of the piles. Colourless pyroxene and epidote and calcite are found. The layer of

Fig. 55. Banded iron ore. Granatinokka, shore of Lake Määrijärvi. $^1/_5$ nat. size.

skarn is nowhere exposed. The nearest outcrops (on the lake-shore) consist of amygdaloidal amphibolite.

The pits known under the name of Vanha Pahalahti mine are only about 10 m deep. In the wall of the northern pit there are two parallel layers in the cordierite-bearing rock: one of andradite-skarn, another of tremolite-skarn with magnetite. North of this pit, along the strike of the layers, there is an exposure of limestone showing the same strike (cf. map. II).

»Banded iron ore.« Magnetite is found at several localities in a zone immediately north of the amphibolite sill near Orijärvi. North of the Orijärvi mine there are two old pits in ore-bearing rock, and one north of Perheentupa, named »Perkiö mine», is located in the same zone.

Iron ore of quite a similar character also occurs at Granatinokka, on the shore of Lake Määrijärvi. The iron ore is markedly banded (fig. 55). Laminae of magnetite, from 1 to 10 mm thick, are intercalated with somewhat thicker laminae of a leptitic rock.

On the microscopical examination of a specimen from the western pit north of the Orijärvi mine, the ore bands were found to be composed of fine-grained m a g n e t i t e and a p a t i t e. A quantitative determination of phosphoric pentoxide in a specimen including several alternating bands gave 2.52 % P_2O_5.

The leptitic laminae are composed of quartz and plagioclase, forming a fine-grained hornfels-mass, and of cummingtonite. The plagioclase is very anorthitic, with at least 80 % An.

This peculiar iron ore is always accompanied by pyrrhotite, pyrite and arsenopyrite. East and west of Perkiö the leptite is impregnated with these sulphide-minerals only, and no magnetite could be detected.

Occurrences of ores outside the Orijärvi aureole.

In the Orijärvi area most occurrences of ores are in the aureole of the oligoclase-granite, as shown on map II. Their common distribution in this aureole and their absence at a longer distance from the granite is indeed a remarkable fact. But there are some exceptions to this rule.

Midway between the villages of Liipola and Haapaniemi, Kisko (see map II), there exists an old pit made in a rock which contains small quantities of copper ore. This occurrence is at the boundary between leptite and porphyritic amphibolite. At the contact both rocks have undergone a complete alteration: The leptite has been converted into a cordierite-bearing quartzose rock impregnated with minute grains of pyrite and chalcopyrite, and the amphibolite into schistose biotite-rock. The pneumatolytic metamorphism cannot have been caused by the leptite or by the amphibolite, but its source must be at a greater depth.

The Aijala mine.

Several small occurrences of sulphides have been found in the villages of Aijala and Lapinkylä. They are all situated along the boundary-line between the blastoporphyritic leptite (p. 132) and agglomeratic leptites intercalated with limestone (see map I). In the western part of the village of Aijala, an ore-bearing layer of limestone and skarn has recently been laid bare. Furthest to the West, the layer of limestone is 8 m thick, and all through contains frequent irregular individuals of pale greyish green diopside, impregnated with small stringes of galenite and sphalerite. At the southern boundary of the limestone one finds a quartz vein or lens, about 1 m thick, containing galenite and smaller amounts of iron pyrites as irregular grains, at most 15 mm in diameter. To the East the layer of limestone tapers out, but the sulphide-bearing zone continues along the boundary of the porphyritic leptite. East of the village there is the old »silver-mine». The adjacent rock is a dark grey leptite. In the rock-piles leptite is prevalent. Coarsely crystalline galenite is associated with dark-green actinolite. According to a private communication from Dr. L. Borgström, the galenite occurs in small lenticular bodies which consist of rich ore, but their irregular distribution prevents any profitable mining.

Magnetometric exploration has proved that magnetic ores exist under the cultivated field east of Aijala, in the same zone as the above occurrences. Probably the magnetic action is caused by pyrrhotite, as further East this mineral occurs near the village of Lapinkylä, still along the same contact. Southeast of Lapinkylä a layer of limestone strikes at right angles to the contact of the porphyritic leptite. Near the contact, the limestone is impregnated with chalcopyrite.

The occurrences of sulphides along the boundary of the porphyritic leptite can hardly be explained as products of the contact-metamorphism caused by the latter, especially as there is no evidence that this rock is intrusive into the leptite-series (cf. p. 134). The porphyritic leptite which generally shows a well preserved primary structure, has just along the boundary between Aijala and Lapinkylä been strongly foliated, in places almost to a mica-schistous rock. This phenomenon probably has something to do with the genesis of the ores.

The Brödtorp mine. The Brödtorp or Nyckeln mine is situated in a fragmentary portion of rocks of the leptite series surrounded on all sides by the oligoclase-granite. The main shaft, made after 1904, is about 35 m deep. The ore-minerals are sphalerite and chalcopyrite in limestone. The exposures round the shaft consist of limestone, leptite and agglomeratic amphibolite, all cut by amphibolite dikes. Diopside skarn occurs near the granite-contact.

Near the Valkjärvi farm, between the oligoclase-granite and the agglomeratic rock (cf. p. 152), the limestone is locally impregnated with arsenopyrite, sphalerite, chalcopyrite and pyrite.

The two last-named occurrences are at the boundaries of the oligoclase-granite. The ores have doubtless originated through a metasomatic replacement of calcite by sulphides.

Several occurrences of magnetite are met with on the estate of Koski, in the parishes of Tenala and Perniö. The most important old mines are Marjaniemi, Storbackan, Perskomböle and Vihiniemi. Still another old iron mine is situated near the village of Baggböle, west of the southern granite batholith. The Vihiniemi mine has been worked to a considerable extent. All the others are rather small pits. *Iron ore in the district of Koski.*

In all these occurrences the narrow laminae of magnetite are intercalated with dark, amphibole-bearing leptitic bands. The ore-bearing layers are bounded by grey leptites. Accompanying minerals are black hornblende and red garnet, probably almandine. Where long-prismatic amphibole and coarsely crystalline pyroxene occur (as at Perskomböle) they show brownish colours suggestive of the ferro-magnesium series of amphiboles and pyroxenes and not of the calcium-bearing species which are usually green-coloured. I have not subjected any specimen from these localities to laboratory examination, but from my field observations I am inclined to think that these occurrences are more closely related to the »banded ore» of the Orijärvi field than to the skarn-ores which occur along the granite contact.

Analogies to the Orijärvi-field in other regions.

Many of the readers of this paper will probably consider the rocks described on previous pages as representing uncommon or quite exceptional formations. This may be especially true of the extreme varieties of rocks occurring here, i. e. the cordierite-anthophyllite-rock. From the geological literature it appears, however, that similar occurrences in other regions are not very rare. Especially in Sweden cordierite- and anthophyllite-bearing rocks, associated with sulphide or oxide ores, are of rather common occurrence. H. E. Johansson was the first to lay stress on the chemical peculiarity of such rocks and to recognize them as an important and independent type.

In 1913 Mr. Trüstedt kindly gave me specimens of sulphide-bearing cordierite-anthophyllite-rock from the Outokumpu copper mine, Kuusjärvi, eastern Finland. In these specimens the cordierite shows crystalline faces towards the sulphides, but it is xenomorphic towards the anthophyllite, just as the Orijärvi cordierite. Picotite was found as microscopical enclosed crystals. It may be mentioned that the area where the Outokumpu mine is situated, is geologically quite different to the Orijärvi region.

Among numerous analogous occurrences in Sweden we may first mention the Falun mine in Dalecarlia. The similarity of the Falun and the Orijärvi ore-bearing rocks was pointed out already by Durocher (9, p. 314). When reading Törnebohm's excellent account of the Falun mine, [1] I was surprised to find the closest analogies in mineralogical, petrographical and geological features between the Falun and the Orijärvi regions.

According to Törnebohm, the rock-crust in the Falun region is chiefly made up of grey granite, diorite, red granite-gneiss, grey gneiss with mica-schist and granulite. Some smaller areas are underlain by red granite, which is of later date than the grey.

The grey granite is oligoclase-bearing and contains dark inclusions. It is partly massive, partly foliated. Thus it shows a close resemblance to the oligoclase-granite of the Orijärvi region. Törnebohm draws a sharp distinction between this granite and the granite-gneiss, but the latter is also granitic in its general habit and both show quite similar relations to the rocks of the leptite series, as indicated on Törnebohm's map. The diorite is older than the granite, but seems to be connected with it, just as in our area. There are also dikes of diorite (=amphibolite) intersecting the grey granite. The grey gneiss with mica-schist occurs chiefly along the boundaries of the grey granite and granite-gneiss, thus being geologically analogous to our leptitic gneiss, which it also resembles petrographically. [2] The granulite is what is now called leptite. Crystalline limestone is found with the granulite in a few places.

At the Falun mine and in its neighbourhood the »grey gneiss» grades into a »quartzite», which is the country-rock of the ores. This rock is composed of quartz, biotite and cordierite, often with anthophyllite. In a thin section of the anthophyllite-bearing Falun quartzite I could verify a perfect similarity with the quartzose cordierite-anthophyllite-rock from the Orijärvi mine. Törnebohm states that rhombic and monoclinic amphibole are often associated. Probably the homoaxial intergrowth of cummingtonite and anthophyllite is to be be found there. In the quartzite the ore minerals (chalcopyrite, pyrite, pyrrhotite) occur quite as in the Orijärvi hard quartzose ore.

The »quartzite» is intersected by thick dikes of »felsite» and »trapp», the latter having intruded also between the felsite and its

[1] A. E. Törnebohm, »Om Falu grufvas geologi», *G. F. F.* 15, p. 609, 1893. See also: Hj. Sjögren, *Guides des excursions en Suède*, n:o 31, 1910.

[2] Sjögren (op. cit. page 3) states that the grey gneiss »shows, on the whole, perfectly granitic characters». This is not in accordance with Törnebohm's description of the grey gneiss (l. c. page 611). Sjögren's statement obviously refers to what Törnebohm calls grey granite.

country-rock so that a kind of composite dikes have resulted. To these rocks we have no analogies in the Orijärvi mine. But, as Törnebohm suggests [1], the felsite dikes may be regarded as fine-grained porphyritic apophyses from the grey granite. Thus the felsite is analogous to the contact-facies of the oligoclase-granite which in the Orijärvi field also occurs as dikes. The trapp dikes are what I have called amphibolite. They show boundary zones containing colourless amphibolite, just as the amphibolite sill near the Orijärvi mine. I found, in a slide of the grey trapp from Falun, that the amphibole was pale brown in colour and optically positive. I venture to believe that, on chemical examination, it will be found to be cummingtonite.

Sköls play an important part in the Falun mine. Törnebohm distinguishes chlorite-sköls, talc sköls and amphibole-sköls, the last-named containing either anthophyllite or monoclinic amphibole. The same kinds of sköls, of quite similar composition, occur in the Orijärvi mine. Skarn rocks, composed of actinolite or diopside, occur in the ore-portions of Falun, and limestone has also been found there. All these rocks are impregnated with abundant sulphides, and are more especially found in the inner portions of the great sulphide-masses.

The Falun ores are technically divided into hard ore, soft ore and gold ore. The first-named is nothing but sulphide-bearing quartzite. The soft ores, which have been found as several enormous masses, are petrographically analogous to the best portions of the Orijärvi soft ore. Finally the gold ore shows an amazing likeness to the Iilijärvi ore. Gold occurs in white quartz and is constantly accompanied by selenium-bearing galeno-bismuthite, often mixed with galenite (note the occurrence of selenium-bearing lillianite associated with gold at Iilijärvi!).

The principal ore-mineral species in Falun and Orijärvi are identical. As further analogies, the occurrence of gahnite in both mines may be mentioned. Andalusite also occurs in the Falun mine.

Differences of a general nature are, that in Falun sphalerite and galenite are comparatively less important than in Orijärvi, while pyrite seems to occur in larger proportion. Another difference is that drusy cavities do not seem to occur in Falun; at least Törnebohm in his very detailed description does not make mention of them.

The Falun mine has yielded over hundred times more copper than the Orijärvi mine. The similarities of the deposits are, however, so close and numerous, that one must conclude that both occurrences have originated through similar processes.

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[1] L. c. pages 613 and 640.

In his report on the Åtvidaberg and Bersbo ore fields, Törnebohm [1] mentions an »actinolite-schist» occurring near the Björkelid copper mine north of Bersbo, East-Gothland. The constituent minerals are yellowish brown »actinolite» and cordierite. »Sometimes actinolite and cordierite may be present in approximately equal amounts, sometimes the former is predominant. Biotite is a minor constituent. This rock, intercalated with garnet-cordierite-schist, fades away into a garnet- and cordierite-bearing gneiss». The »actinolite» is doubtless nothing but cummingtonite, and the rock may be regarded as closely analogous to the cummingtonite-bearing anthophyllite-cordierite-rock of Orijärvi.

In the Långfall mine near Räfvåla, Dalecarlia, sphalerite with some chalcopyrite, iron pyrites and galenite occurs in cordierite-cummingtonite-rock, as described by R. Beck. [2] This author was the first to recognize the presence of monoclinic iron-magnesium amphibole in the sulphide-bearing rocks of Sweden. The amphibole, whose composition was ascertained through a chemical analysis, was called by Beck amphibole-anthophyllite. It was light greyish brown in colour and showed in prismatic sections extinction angles up to 6° only. Green spinel (gahnite?) was also present.

The association of sulphide ores with rocks containing gedrite, anthophyllite or cummingtonite (»clino-anthophyllite») and cordierite, is well known to H. E. Johansson. In his treatise on the Grängesberg iron ore-field, [3] he describes a cordierite-gedrite-plagioclase-gneiss from Blötberget, and remarks: »Derselbe chemische Gesteinscharacter ist nun in manchen anderen Teilen der mittelschwedischen Eisenerzformation von mir beobachtet worden z. B. auf Getön bei Persberg, in gewissen Gesteinszügen bei Striberg und Bispberg und in vielen Sulphiderzbezirken; in seinen extremsten Formen wird er in der Gegend von Westanfors angetroffen.» In another paper [4] the same author lays stress on the association of cordierite and anthophyllite with the sulphide ores. Johansson also describes a »clinoanthophyllite-amphibolite» [5] from the Grängesberg region. This rock is quite identical with many of the cummingtonite-amphibolites in the Orijärvi region.

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[1] »Om de geologiska förhållandena i trakten kring Åtvidaberg och Bersbo». *G. F. F.* ,7, p. 570, 1885.

[2] »Ueber die Gesteine der Zinkblendelagerstätte Långfallsgrube bei Räfvåla in Schweden». *T. M. P. M.* **20**, p. 382, 1901.

[3] »Die eisenerzführende Formation in der Gegend von Grängesberg», *G. F. F.* **32**, p. 239, 1910.

[4] *G. F. F.* **29**, p. 157, 1907.

[5] *G. F. F.* **32**, p. 313, 1910

»Quartz-gedrite-rock» and »quartz-amphibolite with amphibole-anthophyllite», in the Flogberget iron ore field, have also been described by Johansson.[1] Analyses of both rocks, made by R. Mauzelius, are given (l. c. p. 414):

I. Quartz-gedrite-rock, Flogberget.

II. Quartz-amphibolite with amphibole-anthophyllite, Flogberget.

	I	II
SiO_2	67.18	53.68
Al_2O_3	10.09	14.25
Fe_2O_3	1.87	1.53
FeO	11.96	12.92
MnO	0.15	0.15
MgO	5.11	5.13
CaO	0.50	6.52
Na_2O	1.47	2.86
K_2O	0.65	0.26
TiO_2	0.10	1.77
P_2O_5	0.01	0.23
S	0.01	0.02
H_2O	0.80	0.71
	99.90	100.03

In the Flogberget field the rocks do not contain cordierite, having too low a percentage of alumina. In other respects the quartz-gedrite-rock shows, in its composition, a close resemblance to the cordierite-anthophyllite-rocks described in the present paper (page 171). The amphibolite with amphibole-anthophyllite is analogous to our cummingtonite-amphibolites (page 221).

From the pre-Cambrian territory of Canada, a cordierite-gedrite-rock, called amphibolite, has been reported by Adams and Barlow.[2] This occurrence is described as follows: »...... an occurrence, which from its position must be considered as the product of the extreme alteration of limestone by a granitic magma, ... occurs along the north shore of Fishtail lake, in the township of Harcourt. .... this mass lies in the granite-gneiss, ... between two long narrow masses of limestone and on their strike. It is apparently a small mass detached

[1] »The Flogberget iron mines», *G. F. F.* **32**, p. 411, 1910. Also in *Guides des excursions en Suède*, n:o 30, 1910.

[2] »Geology of the Haliburton and Bancroft areas», Memoir N:o 6, *Canada Departement of Mines, Geol. Survey Branch*, p. 170, 1910.

from them, and very highly altered by the granite magma which envelops it. The amphibolite is a dark basic variety, consisting largely of anthophyllite and garnet, associated with cordierite and subordinate amounts of quartz, biotite, iron ore, and rutile». According to an analysis made by N. Norton Evans, the orthorhombic amphibole is gedrite, containing 16.04 % Al_2O_3. It is optically negative. No sulphide ores are mentioned. The authors remark that this is the first occurrence of cordierite and gedrite which has been found in Canada.

Among Central European localities which resemble the Orijärvi field we shall only mention Bodenmais in Bavaria, described by Weinschenk. [1] The exogeneous contact-zone of a granite mass is built up of a rock which Weinschenk regards as a cordierite-hornfels. This rock is composed of cordierite, quartz, sillimanite, biotite, ilmenite and rutile. Almandine often occurs in large quantities. Feldspars are subordinate or entirely absent. The cordierite occurs as xenoblastic grains and is of a later date than the folding of the rock. This rock is injected with narrow veins of light-coloured granulitic granite in which cordierite occurs as idiomorphic crystals, suggestive of assimilation of the hornfels and recrystallization from the magma. Lenticular masses of pyrrhotite with subordinate chalcopyrite, sphalerite and galenite occur in this rock. The sulphide masses contain only small amounts of gangue minerals, such as quartz, cordierite, hypersthene and, rarely, andalusite. Gahnite (kreittonite) is abundant, occurring as boundary-zones between the ore bodies and the wall-rock, which, in the vicinity of the ore, is also impregnated with this mineral. The ore minerals show a marked order of crystallization: the chalcopyrite forms the last crystallized portion. The siliceous minerals, on the other hand, have idiomorphic though corroded forms, and they are often surrounded on all sides by the sulphides. Drusy cavities do not occur.

These characteristics afford many analogies to the Orijärvi field, but also some important differences. Intrusive granite veins do not occur in the cordierite-rocks at Orijärvi. The cordierite-hornfels of Bodenmais resembles many Orijärvi rocks, in being free from lime- and soda-bearing minerals and in its variability, but it seems to be poorer in (Mg,Fe)O. The sulphide bodies in Bodenmais have a more pronounced magmatic intrusive character than the Orijärvi ores

[1] Ernst Weinschenk, »Die Kieslagerstätte im Silberberg bei Bodenmais. Ein Beitrag zur Entstehungsgeschichte der ,Fahlbänder'». *Abhandlungen der mathem.-phys. Classe der Königl. Bayerischen Akademie der Wissenschaften*, **21**, p. 351—409, 1901.

or any of the Swedish occurrences which were mentioned above, the Falun mine not excluded.

Skarn-rocks, similar to those described before, are of such common occurrence in the Archaean territories of Fenno-Scandia that special reference is not necessary here. They are accompanied either by sulphide or by oxide ores. A celebrated example of the former group of skarn ores is the Sala mine in Upland, Sweden. [1] Diopside-skarn and actinolite-skarn are represented there. In the Persberg mining field [2] are found all the different kinds of hornblende-, pyroxene- and andradite-skarn which occur in the Orijärvi field. Where oxide and sulphide ores occur in one and the same ore-field, as in Dannemora, [3] the latter are found to be of later origin than the former.

It may be noted that all the afore-mentioned ore-fields of Central Sweden occur in the neighbourhood of metamorphic Archaean granites (»primary granites», Swedish »urgraniter»). In this respect also they resemble the Orijärvi area.

In Finland we have the Pitkäranta ore-field [4] where skarn rocks occur on a large scale, and both sulphide and oxide ores are associated with these. In other respects the Pitkäranta region has little resemblance of the Orijärvi-field.

The skarn belongs to a type of rocks which is universally represented in contact-metasomatic formations, in all parts of the world. [5] The cordierite-anthophyllite-rock series, on the other hand, seems to be of more limited occurrence, though rocks of similar composition are probably more common than is known at present. It must be noted that cummingtonite may be present instead of anthophyllite, and that the former mineral probably has in very many cases been taken for actinolite (e. g. in the »Garbenschiefer» in Kupferberg, Schlesien?). Moreover, if the minerals originate at higher temperaturres, hypersthene is formed instead of the amphiboles (Bodenmais). Finally, and this is probably a very common case, almandine may have originated instead of cordierite and anthophyllite (Broken Hills, N. S. Wales).

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[1] Hj. Sjögren, »The Sala mine». *G. F. F.* **32**, p. 1363, 1910.

[2] A. E. Törnebohm, »Geognostisk beskrifning öfver Persbergets gruffält». *Sveriges Geol. Unders. Ser. C*, N:o **14**. — Hj. Sjögren, »The Persberg Mines», *G. F. F.* **32**, 1327, 1910.

[3] A. E. Törnebohm, »Beskrifning till geologisk atlas öfver Dannemora grufvor». Stockholm 1878. — Hj. Sjögren, »The Dannemora Mining-field», *Guides des excursions en Suède*, N:o 27, 1910.

[4] O. Trüstedt, »Die Erzlagerstätten von Pitkäranta am Ladoga See», *Bull. Comm. Géol. Finl.* **19**, 1907.

[5] V. M. Goldschmidt (»Die Kontaktmetamorphose im Kristianiagebiet», pp. 220—226) gives reference to several skarn-ore-fields of the world.

General conclusions concerning the origin of the rocks of the Orijärvi aureole.

Among the variegated rocks of the Orijärvi aureole, the skarn-rocks form a well defined group: The skarns are composed merely of calcium-bearing mafic minerals and are closely associated with limestones, having been formed of the latter rocks by metasomatic replacement, whereby iron, magnesia and silica have been added to the rock. This definition agrees entirely with that of V. M. Goldschmidt, [1] except that, according to my conclusions, in certain cases magnesia must also have been added, while Goldschmidt knows only of the iron skarn. In the Orijärvi area there is the tremolite-skarn which is no less a metasomatic product of limestone than the andradite-hedenbergite-skarn.

H. E. Johansson, who regards the skarns as igneous rocks, includes in them the anthophyllite- or cummingtonite-bearing rocks also. In my opinion, this definition causes confusion. Nothwithstanding the theoretical speculations as to their origin, the connection of the lime-bearing skarn-rocks with the limestone is apparent from observation in the field, while the ferromagnesium amphiboles occur in quite another paragenesis.

The magnetite is an ordinary constituent of the skarn-rocks, and probably is syngenetic with them, i. e. has its origin due to the same metasomatic action.

The origin of the other rocks of the aureole is much more difficult to explain. Their most striking feature is, in fact, their frequent and irregular variability. There are all degrees of transition from rocks of an ordinary leptitic composition to certain extreme types. When about to discuss the origin of these rocks, it seems most appropriate to start from these extreme varieties, such as (1) the cordierite-anthophyllite-rock, nearly devoid of quartz, and (2) the quartzose rock with a little cordierite and anthophyllite.

The cordierite-anthophyllite-rock.

The first type is represented by the Träskböle rock and related rocks in the Orijärvi aureole.

In discussing the nature of the cordierite-anthophyllite-rock, the possibility that it is of sedimentary origin with its bulk composition unchanged, may be left out of consideration, as no such sediments of modern date actually exist. Such an excess of alumina as is present here, would indicate complete chemical decomposition of older rocks and is very common in clayey sediments. But I have not found

[1] »Die Kontaktmetamorphose im Kristianiagebiet», p. 213.

among the available analyses of sedimentary rocks [1] any one example showing such high percentages of both ferrous oxide and magnesia and an almost complete absence of lime, soda and potash.

Many features in the geological occurrence of the cordierite-anthophyllite-rock resemble those of igneous bodies: Thus the Träskböle rock-mass shows the form of a laccolith. On the island of Vähäholma (p. 187) anthophyllite-cordierite-rock occurs in the form of a sill. But the chemical and mineralogical composition is thoroughly alien to most igneous rocks.

So far as known to the present writer, only one igneous rock has been analyzed whose composition resembles the rock in question. It is the »laanilite» from Laanila, Finnish Lapland, analyzed by N. Sahlbom [2] (I). For comparison we give the analysis of the cordierite-anthophyllite-rock from Träskböle (II):

	I	II
SiO_2	49.83	48.00
Al_2O_3	18.35	18.62
Fe_2O_3	2.88	1.07
FeO	16.78	16.18
MnO	0.25	0.13
MgO	6.86	11.85
CaO	1.32	0.64
Na_2O	1.09	0.23
K_2O	1.09	0.01
TiO_2	1.39	2.06
P_2O_5	trace	0.09
V_2O_3	—	0.04
Fe_7S_8	—	0.15
H_2O	0.85	1.50
	100.69	100.57

The laanilite occurs, according to private information from Professor Sederholm, as an irregular vein in the »granulite-formation» of Lapland and grades into pegmatite. Sederholm believes that the laanilite has been solidified by crystallization from an aquo-igneous flux which has assimilated materials from the surrounding rocks where disseminated garnet is also abundant. The laanilite is composed of

[1] J. M. van Bemmelen, *Zs. anorg. Chem.* **66**, p. 322, 1910. — F. W. Clarke, *U. S. G. S. Bull.* **419**, 1910. — G. Linck, *Geol. Rundschau*, IV, p. 289, 1913.
[2] V. Hackman, *Bull. Comm. Géol. Finl.* **15**, p. 105, 1905.

garnet, biotite, quartz and iron ores. The agreement of analyses I and II is close, except that the one of laanilite shows a higher percentage of ferrous oxide and a lower of magnesia. In this respect also the laanilite certainly would agree with the garnet-bearing varieties of the cordierite-anthophyllite-rock (cf. p. 195).

It seems to me, however, that in this case the chemical characters do not suffice to decide, wether the rocks are of an igneous origin or not. It may be considered that there is no sharp distinction between true magmas and aqueous solutions under great pressure. The question is better defined as follows: Has the rock-mass crystallized at once from a large mass of solution, or have the minerals gradually replaced earlier constituents? An answer to this question can only be found from the structural characters of the rock.

The actual structure of the cordierite-anthophyllite-rock is doubtless metamorphic and not that of any igneous rock. The order of idiomorphism is controled by the crystalloblastic relations between the minerals, and independent of their quantitative proportions. The diablastic intergrowth of cordierite and anthophyllite, and the occurrence of rounded inclusions of quartz are very characteristic in this respect. In the almandine of the Träskböle rock such inclusions are arranged in parallel rows (p. 179), a feature which may be understood as a relic of an earlier structure (helicite). The rock had been foliated or laminated before the crystallization of the garnet.

Cordierite is found in igneous as well as in metamorphic rocks. In the former case it is usually idiomorphic, while the cordierite in the rock in question is always typically xenomorphic. The anthophyllite is only present in rocks which are generally regarded as metamorphic.

Considering the metamorphic habit of the rock in question in connection with its exceptional bulk composition, it seems justifiable to conclude, that the metamorphism has involved a considerable change of the chemical composition. Iron and magnesium must have replaced calcium, sodium and potassium. For no primary rocks are at the same time so rich in iron and magnesium and nearly devoid of the other just named elements. In other words, the cordierite-anthophyllite-rock must be the product of an extreme metasomatic alteration of earlier rocks of whose original composition we have no evidence.

The conversion of the plagioclase minerals into cordierite, a reaction which evidently plays an important part in this metasomatic alteration, may be expressed through the following formulas:

1) $4NaAlSi_3O_8+2MgO=Mg_2Al_4Si_5O_{18}+7SiO_2+2Na_2O$.
2) $2CaAl_2Si_2O_8+2MgO+SiO_2=Mg_2Al_4Si_5O_{18}+2CaO$.

Thus the plagioclases can be totally converted into cordierite through a replacement of soda and lime by magnesia and ferrous oxide, without any addition of alumina. The formation of anthophyllite besides cordierite implies further addition of magnesia and iron.

There are gradual transitions between the cordierite-anthophyllite-rocks and the leptites, i. e. rocks composed chiefly of quartz and feldspars with small amounts of mica or hornblende. The first stage of the transition from the leptite is the replacement of potash feldspar by biotite. In the plagioclase-gneiss (p. 218) and in all cordierite- or andalusite-bearing rocks of the Orijärvi aureole no potash feldspar was ever observed. At a farther stage the cordierite appears, and subsequently the anthophyllite. At the same time the amount of plagioclase diminishes and, in true cordierite-anthophyllite-rocks, it is entirely absent. In many cases quartz also is very scarce, but more often present in considerable amounts.

The cordierite-gneisses and the cordierite-anthophyllite-gneisses may present the same chemical composition as some hornfels-rocks which were originally argillaceous sediments. And, as we have seen, such true sedimentogeneous rocks may also be identical with these rocks in their mineral composition (p. 149). It appears from what was said above that they must not necessarily be explained in such a way, but that they may present intermediate stages in the alteration of the leptites or other siliceous rocks into cordierite-anthophyllite-rocks.

The gradual transition frequently takes place in the direction of the strike, as seen in fig. 41 page 201. On a larger scale the same phenomenon is seen near the farm of Paavo (map II): the cordierite-bearing rocks fade away into common leptites, very poor in mafic constituents. In the continuation of the stratigraphical zone to which the cordierite-anthophyllite-rocks belong, no rocks of such a composition were found outside the aureole, neither east nor west.

This fact is doubtless in favour of the supposition that the whole cordierite-bearing zone owes its actual composition to a pneumatolytic metamorphism.

It seems to me, moreover, that this hypothesis is not by any means disagreable with the structure of the rocks. The frequent accumulation of the cordierite as groups of colossal crystals proves in fact that the compounds of this mineral posses a considerable capacity of circulating in rocks.

On the island of Kurksaari the large crystals of cordierite contain inclusions of quartz in parallel rows (p. 206), often oblique or transversal to the direction of the elongation of the crystals. This phenomenon can be explained as a helicitic structure. Further illustration as to the origin of the cordierite is afforded by the phenomena which were observed at the contacts of the apatite-bearing fragments enclosed in the cordierite-anthophyllite-gneiss of Kurksaari (p. 208): The cordierite had continued to grow some distance into the apatite-leptite, obliterating the plagioclase, while quartz and apatite had become enclosed in the cordierite.

Full evidence cannot, however, be afforded as to the pneumatolytic origin of all cordierite-bearing rocks of the contact-aureole. The occurrence of rocks of a similar composition and clearly of a sedimentary origin (p. 148) in this same tract is a fact which must not be disregarded. The irregularity in the strata and the variability in composition can be ascribed to the fact that there has been volcanic activity in the Orijärvi field during the time of the sedimentation.

As a summary, we may state that the composition and structure of the true cordierite-anthophyllite-rocks are most in favour of the opinion that they have originated through metasomatic processes which have caused considerable changes in their composition, while the question as to the origin of the cordierite-anthophyllite-gneiss and the cordierite-gneiss must still remain unanswered.

The »ore-quartzite». The cordierite-anthophyllite-rocks grade frequently into varieties very rich in quartz, so that their bulk composition approaches that of quartzites. In certain types the anthophyllite is absent (the quartz-cordierite-rock, p. 209). In the Orijärvi area, such quartzose rocks occur near the Orijärvi mine and usually contain sulphide-minerals. Similar rocks are met with in other regions. At the Falun mine such cordierite-bearing quartzites seem to play a more important part than in the area in question.

Former investigators have usually termed these rocks quartzites and regarded them to be of a sedimentary origin. In my opinion, this interpretation is improbable. Considering the Orijärvi area only, there are several reasons for this: (1) No quartzites have been observed within the leptite-belt outside the Orijärvi aureole. (2) These quartzitic rocks are intimately associated with cordierite-anthophyllite-rocks devoid of feldspars and show frequent transition into the latter. (3) They contain cordierite and (usually) anthophyllite, i. e. magnesium-bearing minerals, while in sedimentary sandstones and quartzites, potassium and iron-bearing minerals are regular minor constituents. (4) Such »quartzites» seem to occur only in association with sulphide-minerals. This paragenesis is so striking, that these rocks might well be termed ore-quartzites, if the term quartzite must be used. (5) Drusy cavities are common in the »hard quartzose rock» of the Orijärvi mine.

In consequense of the above statements, it seems to me that the quartzose cordierite-bearing rocks have also originated from leptitic rocks through a metasomatic replacement of the feldspars with quartz.

The andalusite bearing quartz-mica-rock.

As to the andalusite-bearing quartz-mica-rock, it was impossible to get any exact idea of its mean composition. Regarding such portions which are free from plagioclase, it seems evident that their composition has changed, at the same time as the peculiar brecciated structure originated. The metasomatosis must have consisted chiefly in an addition of silica and removal of lime and soda. At certain points an addition of considerable amounts of potash is probable (p. 217). The excess in alumina may be a residual part of that alumina which originally had entered into the feldspars. The concentration of andalusite in certain irregularly distributed spots (p. 213) affords strong evidence for the opinion that circulation of substance has taken place on a large scale.

I do not know of any occurrence in other regions resembling this particular rock-type. A certain analogy to the g r e i s e n, however, is quite evident.

The cummingtonite-amphibolite.

The bleached, cummingtonite-bearing amphibolites which occur as a narrow boundary-zone of the Orijärvi amphibolite sill and in the western part of the Määrijärvi basin, have probably been derived from normal amphibolites in such a way that cummingtonite has been formed instead of the hornblende, i. e. the »femic lime» has been replaced by magnesia and ferrous oxide. The evidence for this opinion was given above (p. 225). Concerning the quite identical phenomena in the »trapp» dikes at Falun, Törnebohm was already led to the conclusion that the »grey trapp» must be an altered facies of the dark-green trapp, and that the metamorphic influence on the dikes had worked »inwards from outwards» and increased towards the centre of the ore-bodies.[1] Törnebohm, however, did not know the chemical nature of the alteration.

The sulphide ores.

The epigenetic nature of the Orijärvi sulphide ores was emphasized already by Wiik. Subsequently Tigerstedt and Trüstedt have given further evidence on this point.

As to the »soft ore», it is quite evident from the previous statements that the sulphides are of later date than the skarn minerals.

[1] *G. F. F.* IV. **15**, p. 635, 1893.

In the case of the hard quartzose rock impregnated with copper ore, it is also obvious that the ores have crystallized at a later epoch than the rock minerals, as the ore often occurs as veinlets or fills up drusy cavities. But a great part of the sulphides are enclosed in the rock as irregular grains, perfectly isolated from each other. The impregnated rock of the Orijärvi mine displays quite the same appearance which, in the Falun »hard ore», forced Törnebohm to believe that the ores must be of a sedimentary origin, as primary as the rock itself, or that the rock had become impregnated with sulphides when it had the consistency of a porous sandstone. If the quartz-cordierite rock is regarded as a sedimentogeneous quartzite, this reasoning seems to me the only logical one. But as it seems probable that the actual composition is due to a metasomatic alteration, it is most natural to think that the sulphides have been carried in by the same vapors which involved the metasomatosis of the rock. Many facts are in favour of this supposition:

1) The cordierite-anthophyllite-rocks and related quartzose rocks are invariably associated with ore-minerals, mostly sulphides, but sometimes oxides. Thus all such rocks in the Orijärvi area contain pyrite, sphalerite or gahnite etc. Many of these minerals, e. g. galenite, gahnite and pyrite, are found as euhedral crystals, enclosed in the cordierite. In the Träskböle rock pyrhotite occurs. The quartzose modifications especially are ore-bearing. The occurrence near Liipola (p. 243) is very characteristic, the quartzose rock having developed quite locally at the contact between the leptite and the amphibolite. In Falun it is a common experience, that »the purer the quartz the richer the ore», while the biotite-bearing »ugly quartz» is known to be ore-free. I might mention some further occurrences in southern Finland, where a grey, greasy-looking cordierite-bearing quartzose rock is impregnated with sulphides. A typical development of such a rock occurs around an old pit in zinc blende near Lågnäs, in the parish of Ingå.

This recurring association can hardly be accidental. If the sulphides were of a later origin than the cordierite-bearing rocks, why should they favour these more than other rocks, and why have the strongest affinity to the quartzose types, which, in all probability, are very impermeable?

2) Sulphides are common in quartz-veins. This fact proves that silicic solutions usually bear sulphides.

From the above considerations we are led to the following theory concerning the genesis of the ores at Orijärvi.

Iron-, magnesia- and silica-bearing vapors or solutions[1] soaked into the leptites round the granite-mass and caused a thorough alteration in their mineral and chemical composition. These vapors also contained heavy metals and sulphur. The sulphides generally did not crystallize contemporaneously with the newly formed cordierite etc., but remained in the residual solution, which still contained much silica. Only smaller amounts were trapped in the cordierite-anthophyllite-rocks. The re-crystallization of the most quartzose varities probably took place at the lowest temperatures, and therefore more sulphides were retained in these portions. Here also the sulphides represented the most soluble portion and, besides residual quartz, filled up the cavities and cracks of the rock. Part of the metal sulphides, however, were filtrated out from the cordierite-bearing rocks and concentrated in the tremolite-skarn and limestone, where conditions for their metasomatic precipitation were favourable.

The chlorite- and talc-sköls, in their actual habit, have probably been formed at the last stage of the pneumatolytical process, when the temperature already was low enough to permit the formation of hydrated minerals. It may be assumed that the residual solutions escaped through the sköls. Still at the present day the ground-water in the Orijärvi mine percolates only along the sköls.[2]

The age of the pneumatolytic metamorphism.

The pneumatolytic metamorphism round the Orijärvi granite has taken place later than the solidification of the boundary-zone of the oligoclase-granite. This is evident from the fact that the contact-facies of the granite at the north-west corner of the batholith has also been altered (p. 213).

Probably this is the regular course of all pneumatolytic contact-metamorphism. The same order is stated also by Goldschmidt in the Christiania region[3] and by A. Bergeat in the aureole round the granodiorite near Concepcion del Oro, Mexico[4].

The amphibolite dikes which intersect the contact-metamorphic rocks as well as the granite itself, are uninfluenced by the pneumatolytic agencies. This is especially remarkable in the northwestern part of the aureole, where all older amphibolitic rocks have been

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[1] It seems impossible to determine, whether the temperature was over the critical point of the emanating substances or not.

[2] Such drifts in the mine where no sköls cut the rock, are wonderfully dry. Thus, in the Nya Ludvigsgrufvan, which is not directly connected vertically with the earth's surface, no water drops from the ceiling.

[3] »Die Contactmetamorphose im Kristianiagebiet», p. 107.

[4] »Der Granodiorit von Concepcion del Oro im Staate Zacatcas (Mexico)». *N. Jahrb. f. Min., Beilage-Bd.* 28, pp. 422—573 1909.

converted into cummingtonite-amphibolites or, in extreme cases, into biotite-cordierite-rocks (p. 218). We have here a positive proof that the metamorphism was earlier than the intrusion of these dikes.

The newer aphibolites, on the other hand, are of earlier date than the microcline-granites (p. 116), being probably not very much later than the oligoclase-granites (cf. p. 15).

There is all sufficient evidence that the pneumatolytic metamorphism was caused by the oligolase-granite, having taken place during its crystallization, when the endogeneous contact-zone had already begun to consolidate.

As we concluded above, the sulphide ores probably owe their origin to the same main factors which caused the general pneumatolytic metamorphism of the rocks. Thus we regard the sulphide ores as the products of a pneumatolytic metamorphism caused by the oligoclase-granite.

This hypothesis, resulting from a series of conclusions based on observation, seems to me the most satisfactory possible. But the problem is complicated, and future investigation may afford new points of view which may lead to some other conclusion, just as already different opinions have been set forth.

Wiik (**17**, p. 87) and Tigerstedt (**26**) regarded the amphibolite as the parent rock of the sulphide ores, noting the position of the richest ore-masses along the amphibolite-wall. This opinion, based on the assumption that the amphibolite would be a true deep-seated intrusive rock (»diorite»), can at present hardly be maintained, especially as observation shows that the sulphides are not restricted to the vicinity of the amphibolite-sill.[1]

Trüstedt has presented another hypothesis (quoted by R. Beck **37** p. 81—84) which indeed deserves the closest attention. We may quote Trüstedt's argument as it is given in Beck's Text-book:

»Jedenfalls hat die von Trüstedt durchgeführte mikroskopische Untersuchung gezeigt, dass die Erze in ihrer jetzt vorliegenden Form erst nach den gewaltigen Pressungen, denen alle dortigen Gesteine, die Hälleflinten (Leptinite), Diorite, wie auch die gneissartig gestreckten Granite, ausgesetzt waren, in die kalksteinreiche Gesteinzone eingewandert sind. Man findet nämlich häufig kataklastisch veränderte Silikate und namentlich Reste von Kalkstein mit geknickten

[1] The amphibolite may, however, have played a part in the genesis of the Orijärvi ores, having functioned as an impermeable wall, along which the ores concentrated.

und verbogenen Zwillingslamellen innerhalb nahezu unveränderter Sulfidmassen, welche offenbar metasomatisch sowohl Kalk- als Silikatsubstanz verdrängt haben. Es liegt daher näher, die Erzbildungen mit den jüngeren, von Pegmatiten begleiteten, wenig deformierten Graniten in genetischen Zusammenhang zu bringen. Diese treten östlich von Orijärvi-See bis über den grossen Lojo-See hinaus, sowie überhaupt im ganzen südwestlichen Finnland in grossen Massen auf.»

The facts mentioned by Trüstedt seem to prove that the ores must be considerably newer than the oligoclase-granite, which is metamorphic (not »gneissartig gestreckt», however. In specimens collected some 150 m south of the mine no foliation whatever can be detected. Cf. page 46). In my opinion, the kataclastic structure in the siliceous minerals and the bended lamellae in the limestone are due to the pneumatolytic intrusion through which the ores originated. Similar phenomena are seen everywhere at the contacts between non-metamorphosed granites and the limestones. Besides, it is quite natural, that there are also traces of stress which took place before the ores crystallized, as the stress must have been most strong just at the time of the intrusion of the granite. The marked foliation of the tremolite-skarn reminds us that this rock has crystallized under stress. Of later movements there are very conspicuous proofs in the sköls, as also in many specimens of the soft ore. It seems natural that no movements took place in the compact rock-portions between the sköls, when we remember that the later metamorphosis was chiefly of a chemical nature, as the structure of the adjacent granite indicates (p. 53).

There are several reasons against the assumption that the ores owe their origin to the newer microcline-granite.

1) The ores would, in that case, have an origin independent of the metamorphism of the rocks of the aureole. This is unlikely (p. 258).

2) The nearest mass of microcline-granite in the earth's surface is situated as far away as 4 km from the Orijärvi mine. Pegmatite dikes, probably connected with this granite, are very rare in the neighbourhood of the mine (see map II).

3) The rare minerals found in the pegmatites, which represent the pneumatolytic extract from the microcline-granite, contain beryllium, columbium, tantalum and tin (pp. 37 and 38), i. e. elements which are thoroughly alien to the Orijärvi ores.

4) In the very numerous localities in the Southwest of Finland, where limestone occurs in direct contact with the microcline-granite,

I have nowhere observed pneumatolytic skarn; in these occurrences sulphide minerals in limestone are found only in traces; the greatest amounts have been observed at Hermala in Lohja. It is, however, to be noted that the limestones of Lohja occur in a leptite area which has been thoroughly injected with the microcline-granite. It is therefore impossible to know what is due to the newest granite and what to older granites which now occur as older gneissose portions of migmatites. In general, the microcline-granites have certainly been very poor metal bearers. This is quite in accordance with the fact that these granites do not show any endogeneous fine-crystalline contact-zones: the wall-rock was no colder than the magma, therefore no condensation of vapors took place.

Sustschinsky (**41** p. 227) also has expressed the opinion that the Orijärvi ores were a product of a contact-metamorphic influence of the Orijärvi granite, but he was unaware of the fact that there are more than one granite in this area. This author believed that he agreed with Trüstedt's hypothesis in regarding the above-named granite as »a common post-Bothnian granite», and overlooked the words »diese treten östlich von Orijärvi auf» (cf. p. 64).

Summary. As a general conclusion, we may state that the rocks of the Orijärvi aureole owe their peculiar characters to pneumatolytic agencies which have caused considerable changes in their composition. These changes have, for the greatest part, consisted in a metasomatic replacement of lime, soda and potash by iron oxides and magnesia. These main features are the same in the alteration of the limestone into skarn, of the leptites or other siliceous rocks into cordierite-anthophyllite rocks, and of the amphibolites into cummingtonite-amphibolites. In some localities the alteration consisted in a considerable enrichment in silica.

Certain rocks, as the amphibolites, offered more resistance to the pneumatolytic agencies than others. A good example is afforded by the amphibolite-mass near the Workmen's Association (p. 100). It seems that the skarn-rocks, which probably originated at the earliest stage of the pneumatolytic action, also resisted further influence, though they still contained lime. In many cases they also protected the leptites with which they are intercalated, so that the latter are, in the midst of the aureole, as fine-grained and non-influenced as ever. This very remarkable phenomenon is fairly evident in several places, e. g. in those illustrated by figures 47, 52 and 53.

The sulphide as well as the oxide ores originated in the same processes by which the rocks assumed their present habit and composition.

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Index of minerals

found in the area covered by map I.

Those numbers which are printed in *italics* refer to pages on which more detailed descriptions of the minerals in question and determinations of their physical or chemical properties are quoted.

Numbers in ordinary type refer to pages on which minerals are only mentioned but not described.

This index also includes such minerals found in the area which are not mentioned elsewhere in the present paper. Reference to the literature, when available, is given in such cases.

Explanation of the Plates.

Plate I.

Fig. 1. Microcline-granite from Sillanpää in Kisko. Crossed nicols. Magnified 15 diameters. Microcline in contact with quartz. The contact-lines show sinuous curvings giving the impression that the microcline has been corroded.

Fig. 2. Microcline-granite from Sillanpää in Kisko. Crossed nicols. Magnified 15 diameters. Minute idiomorphic grains of microcline enclosed in quartz and showing forms which are less detached by corrosion than the larger crystals. In the right hand side the irregularly curved joining between two individual grains of quartz is seen and a faintly undulatory extinction appears in one of the grains.

Fig. 3. Myrmekite in the microcline-granite from Metsänoja in Perniö. Crossed nicols. Magnified 36 diameters. The myrmekite is idiomorphic with rectilinear boundaries and is turbid but bordered by a clear zone without any quartz. It is bounded by microcline except in the upper left hand side where a large grain of quartz is seen, and in the top side where a corroded crystal of lepidomelane is partly enclosed in the myrmekite.

Fig. 4. Oligoclase-granite, west of Salmi, Orijärvi, Kisko. Crossed nicols. Magnified 15 diameters. In the right hand half is seen a quartz-grain showing distinct strain shadows, and in the central part an idiomorphic crystal of plagioclase (dark). The strongly granulated structure of the rock is visible.

Fig. 5. Hornblende-gabbro from Sepänlampi, Hauksuo, Kisko. Crossed nicols. Magnified 15 diameters. Chiefly hornblende and plagioclase. The idiomorphism of the plagioclase towards the hornblende is best seen in the central parts. The hornblende is partly opaque from black pigment, as may be seen in the middle of a grain which bounds an idiomorphic crystal of plagioclase below the centre of the figure.

Fig. 6. Hornblende-gabbro from Mäkijärvi, Kisko. Unpolarized light. Magnified 15 diameters. In the centre is a grain of leucoxene, the grey portions consist of titanite, and the black bars are ilmenite. This grain is surrounded by a group of biotite scales. In the top side is biotite forming the border of another group around a kernel of leucoxene. The scattered dark grains are newly formed hornblende in plagioclase.

Plate II.

Fig. 1. Blastoporphyritic amphibolite from Riilahden Sorro, Kisko. Unpolarized light. Magnified 15 diameters. Phenocrysts of plagioclase and uralite (left hand bottom side) in a granoblastic ground-mass of plagioclase

and hornblende. The phenocrysts show fringed outlines due to the recrystallization of the ground-mass grains, and prisms of hornblende have grown into the plagioclase.

Fig. 2. Blastoporphyritic amphibolite, northeast of Liipola, Kisko. Crossed nicols. Magnified 15 diameters. Idiomorphic phenocrysts of plagioclase, showing zonal structure, in a granoblastic ground-mass of plagioclase and hornblende.

Fig. 3. Amygdaloidal amphibolite from Valvinokka, Kisko. Unpolarized light. Magnified 15 diameters. In the centre an amygdule, whose central part consists of calcite surrounded by a shell of diopside. In other parts of the figure are seen phenocrysts of plagioclase like those shown in fig. 1.

Fig. 4. Amphibolite from the sill north of Lake Orijärvi. Crossed nicols. Magnified 36 diameters. Idioblastic prisms of hornblende with cummingtonite in a mass of polygonal plagioclase-grains, many of which show an inverse zonal structure, well visible in the centre of the figure.

Fig. 5. Amphibolite from a dike near the cottage of Grönqvist, Orijärvi, Kisko. Unpolarized light, magnified 15 diameters. The granoblastic mass of plagioclase and hornblende shows a parallel structure along the direction of the dike and, at right angles to this direction, a secondary folding and shearing-planes which are parallel to the schistosity of the country-rock.

Fig. 6. Diopside-amphibolite west of the road between Orijärvi and Vetjo, Kisko. Unpolarized light. Magnified 15 diameters. Large skeletal crystals of diopside (grey) and prisms and groups of hornblende (darker) in a mass of plagioclase and microcline (light).

Plate III.

Fig. 1. Quartz-porphyritic leptite from Lapinkylä, Kisko. Crossed nicols. Magnified 15 diameters. In a granoblastic hornfels-mass of quartz, microcline and biotite are embedded phenocrysts of quartz and feldspars. Two crystals of quartz are visible showing hexagonal cross-sections with somewhat corroded and fringed outlines. A phenocryst of plagioclase, much altered, is seen in the left hand side.

Fig. 2. Blastoporphyritic leptite from Liipola, Kisko. Crossed nicols. Magnified 15 diameters. Granulated phenocrysts of plagioclase in a hornfels of plagioclase, quartz and biotite.

Fig. 3. Leptite from Vetjo, Kisko. Unpolarized light. Magnified 15 diameters. Prisms of hornblende in a quartz-feldspar mass. In the left hand top corner is seen a fragment-like inclusion consisting of quartz and feldspar. The light field visible in the bottom side is an aggregate of quartz-grains.

Fig. 4. Leptite, south of Aijala, Kisko. Crossed nicols. Magnified 15 diameters. In the left hand side of the central parts is a crystal of plagioclase, and the two other light spots are bipyramidal crystals of quartz.

Fig. 5. Andradite-skarn from Tarklahti, Orijärvi, Kisko. Unpolarized light. Magnified 15 diameters. Black = magnetite; dark grey rounded grains = andradite; pale grey large individuals = hedenbergite; white = quartz and calcite.

Fig. 6. Hedenbergite-skarn from Perheentupa, Orijärvi, Kisko. Unpolarized light. Magnified 15 diameters. Grey = hedenbergite; white = quartz. The pyroxene is, to a slight degree, altered into green hornblende which is visible as darker portions.

Plate IV.

Fig. 1. Cummingtonite-amphibolite from the boundary of the cordierite-anthophyllite-rock near Träskböle, Perniö. Crossed nicols. Magnified 27 diameters. Plagioclase, cummingtonite & anthophyllite, biotite and ilmenite. In the centre is a prism of amphibole cut || (010); the middle part of this prism is cummingtonite and on both sides are laths of anthophyllite intergrown with the former. The large prisms in the right hand top corner are cummingtonite. Biotite (grey with dark halos) is seen around the right hand end of the amphibole in the centre of the figure.

Fig. 2. The contact of porphyroblastic cordierite-anthophyllite-gneiss and a fragment of apatite-leptite from the island of Kurksaari, Kisko. Crossed nicols. Magnified 30 diameters. The contact-line is seen in nearly vertical position in the middle of the figure, and the leptite is in the right hand side. The individual crystal of cordierite which occupies the left hand half, has grown into the leptite, and its actual border is not far from the right hand margin of the figure. The cordierite has replaced all the plagioclase and part of the quartz of the leptite, while the larger grains of quartz and the small rounded prisms of apatite have been enclosed in the cordierite. The apatite crystals, which are as abundant as in the leptitic framents, are well visible near the original contact-line.

Fig. 3. Andalusite from the Iilijärvi mine, cut || (001), with included crystals of biotite (dark) and minute heart-shaped twins of rutile. Unpolarized light. Magnified 13 diameters.

Fig. 4. Zinc ore from the Orijärvi mine (»Lindsay-mine»). Unpolarized light. Magnified 16 diameters. In the left hand half are seen corroded prisms of tremolite whose interstices have been filled up with sphalerite. The mineral in the right hand side is gahnite with corroded inclusions of tremolite. Sphalerite also fills up cracks in the gahnite.

Fig. 5. Zinc ore from the Orijärvi mine. Unpolarized light. Magnified 16 diameters. Fragments of tremolite prisms are embedded in sphalerite.

Fig. 6. »Hard ore» from the Orijärvi mine (»Västra grufvan»). Unpolarized light. Magnified 16 diameters. Polygonal grains of quartz and chalcopyrite and larger prisms of cummingtonite & anthophyllite.

Plate V.

Fig. 1. Cordierite-anthophyllite-gneiss from Kurksaari, Kisko. Unpolarized light. Magnified 35 diameters. In a large porphyroblast of cordierite are enclosed grains of quartz (not visible) and ilmenite (black) and larger prisms of cummingtonite & anthophyllite.

Fig. 2. The same between crossed Nicols. The inclusions of quartz are visible. The largest amphibole prism is seen to be composed of anthophyllite, which forms the marginal portions, and cummingtonite, forming the central part and showing twinning lamellae.

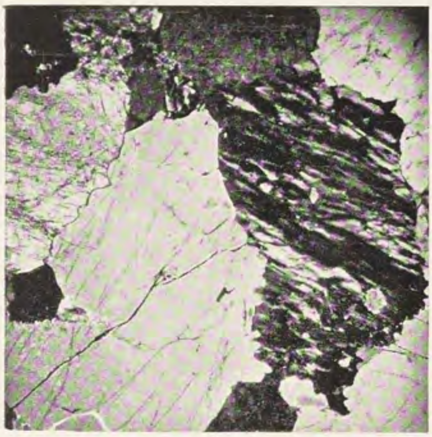
Plate VI.

Cordierite-anthophyllite-rock from Träskböle, Perniö. Radiating groups of anthophyllite whose interspaces are made up of cordierite.

Errata.

Page 34	explanation of fig. 5	*for*	mat.	*read*	nat.
» 41	line 1 from bottom	»	76.8	»	77.8
» 54	table IV, Mol. prop. of MnO	»	.061	»	.001
» 58	line 12 from top	»	composition the	»	the composition
» 61	» 9 » bottom	»	page 87	»	page 187
» 63	» 7 » top	»	13.52	»	13.31
» 70	» 10 » bottom	»	XIII	»	VIII
» 71	table VIII, Mol % of CaO	»	10.7	»	11.6
» »	line 3 from bottom	*after*	(Ab_{56} An_{44})	*add*	;
» 72	table IX, last column, % H_2O	*for*	0.05	*read*	0.85
» 79	line 12 from bottom	»	is are	»	is
» 110	table XVIII last column	»	.850	»	.750
» »	» » next last column	»	.057	»	.047
» 111	line 6 from bottom	»	by (110)	»	by (100)
» 120	» 7 » »	»	Ab_{85} An_{15}	»	Ab_{15} An_{85}
» 130	» 7 » top	*after*	Hornung	*add*	[2]
» »	second footnote	*for*	[1]	*read*	[2]
» 132	table XX, Mol. prop. of CaO	»	.041	»	.014
» 136	line 19 from bottom	»	ben	»	be
» 139	» 18 » top	»	indivdual	»	individual
» 140	» 5 » »	»	(p. 136)	»	(p. 132)
» 145	» 18 » bottom	*below*	k	*add*	2.00
» 153	table XXVI, Mol. % of SiO_2	*for*	99.9	*read*	66.9
» 176	» XXX, column II, % of FeO	»	22.18	»	22.86
» »	» » » » sum	»	100.54	»	100.31
» 177	line 14 from top	»	1.776	»	1.667
» »	» 15 » »	»	1.767	»	1.676
» 187	» 11 » bottom	»	(fig. 47)	»	(fig. 39)
» 192	table XXXII, % FeO. second line	»	22.18	»	22.86
» 201	explanation of the figure	»	Fig. 49	»	Fig. 41
» 208	line 13 from bottom	»	pl. V, fig. 1	»	pl. IV, fig. 2
» 213	» 2 » top	»	fig. 52	»	fig. 47
» 215	» 7 » »	»	fig. 54	»	fig. 47
» 227	» 10 » »	»	2.36	»	2.63
» 230	» 1 » bottom	»	pl. IV	»	pl. III
» 231	table XVII, Mol. prop. of SiO_2	»	$\left.\begin{matrix}0.601\\.005\end{matrix}\right\}$ 0.606	»	$\left.\begin{matrix}0.614\\.005\end{matrix}\right\}$ 0.619
» »	line 14 from bottom	»	3.108	»	3.175
» 238	» 18 » top	»	fig. 3	»	fig. 4
» »	» 20 » »	»	fig. 4	»	fig. 5
	Map II, explanation of the colours,	»	cummingtonitite	»	cummingtonite-amphibolite

Pl. I.



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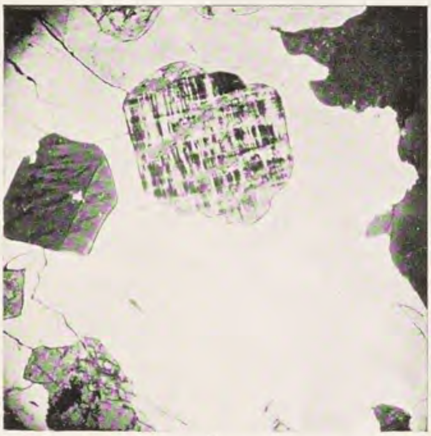

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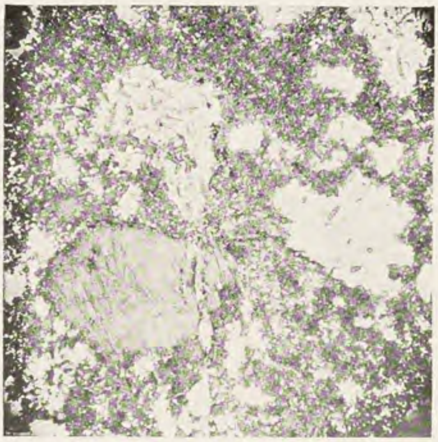
Eskola, Orijärvi Region

Pl. II.



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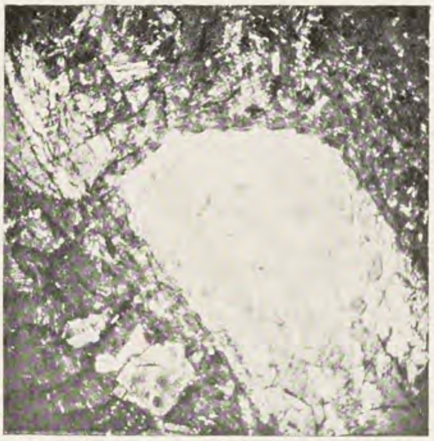

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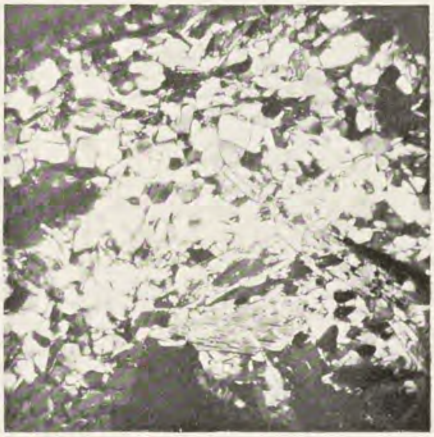

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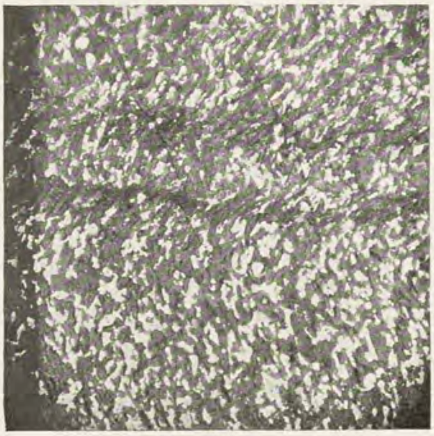

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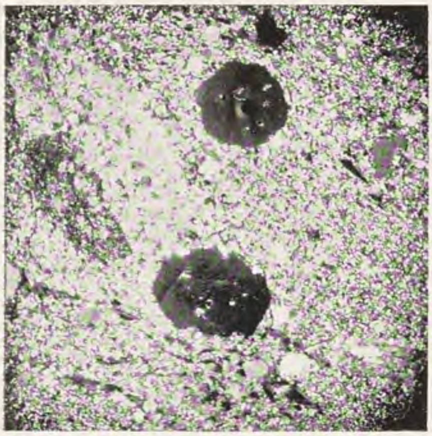
Eskola, Orijärvi Region



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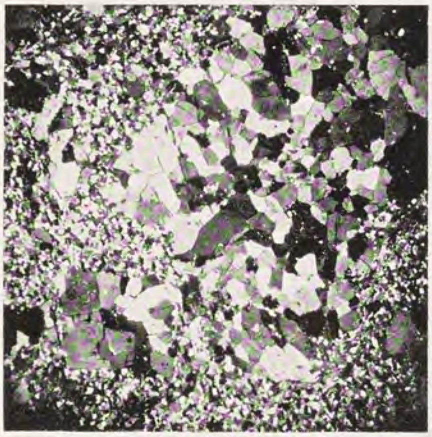

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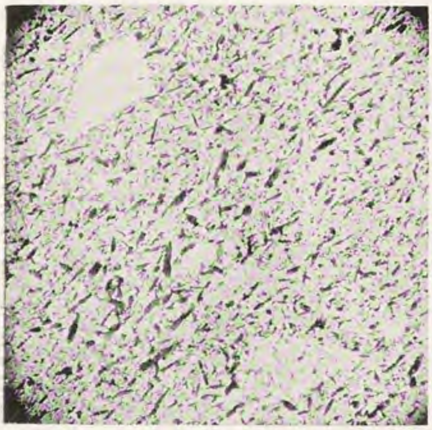

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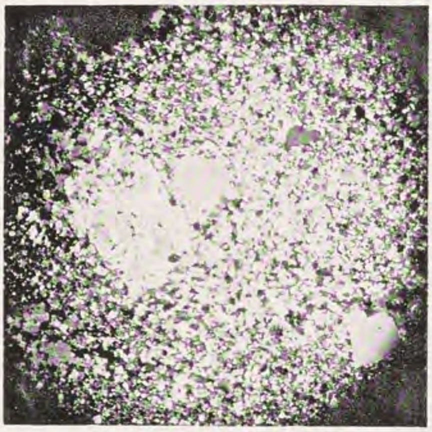
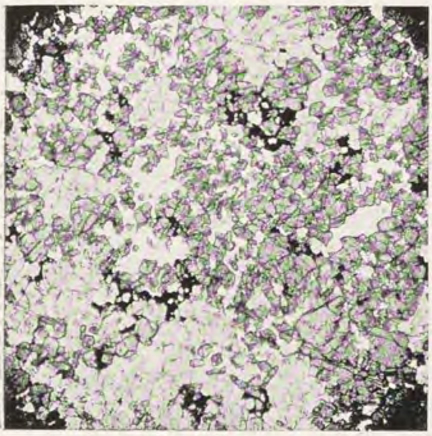


4



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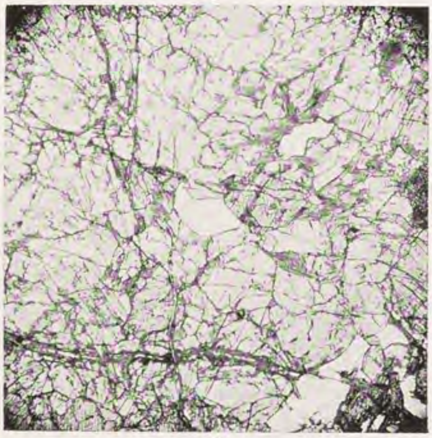
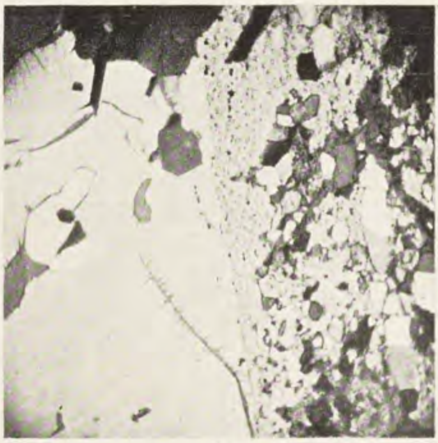


6

Pl. IV.

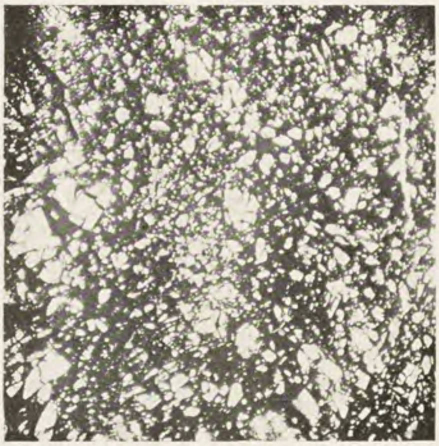
1



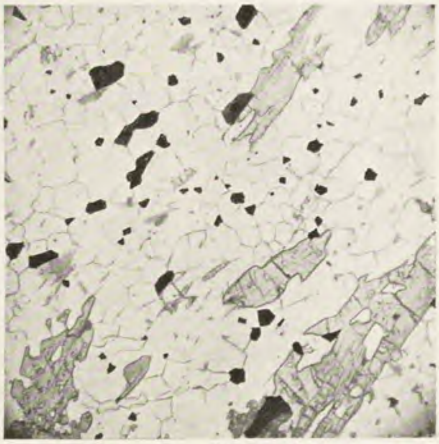
2

3

4

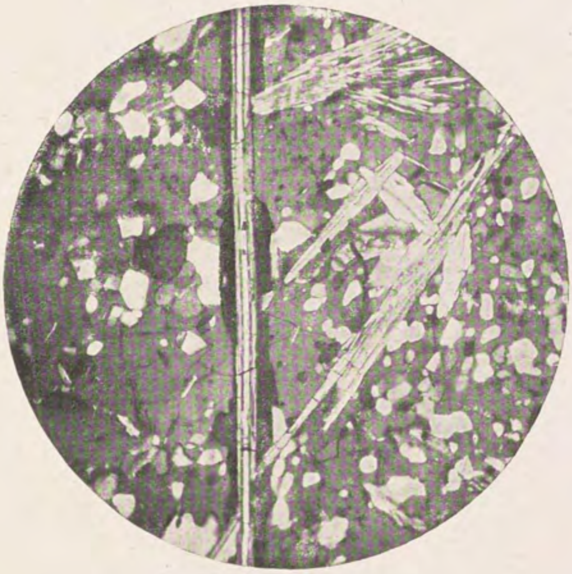


5



6

1

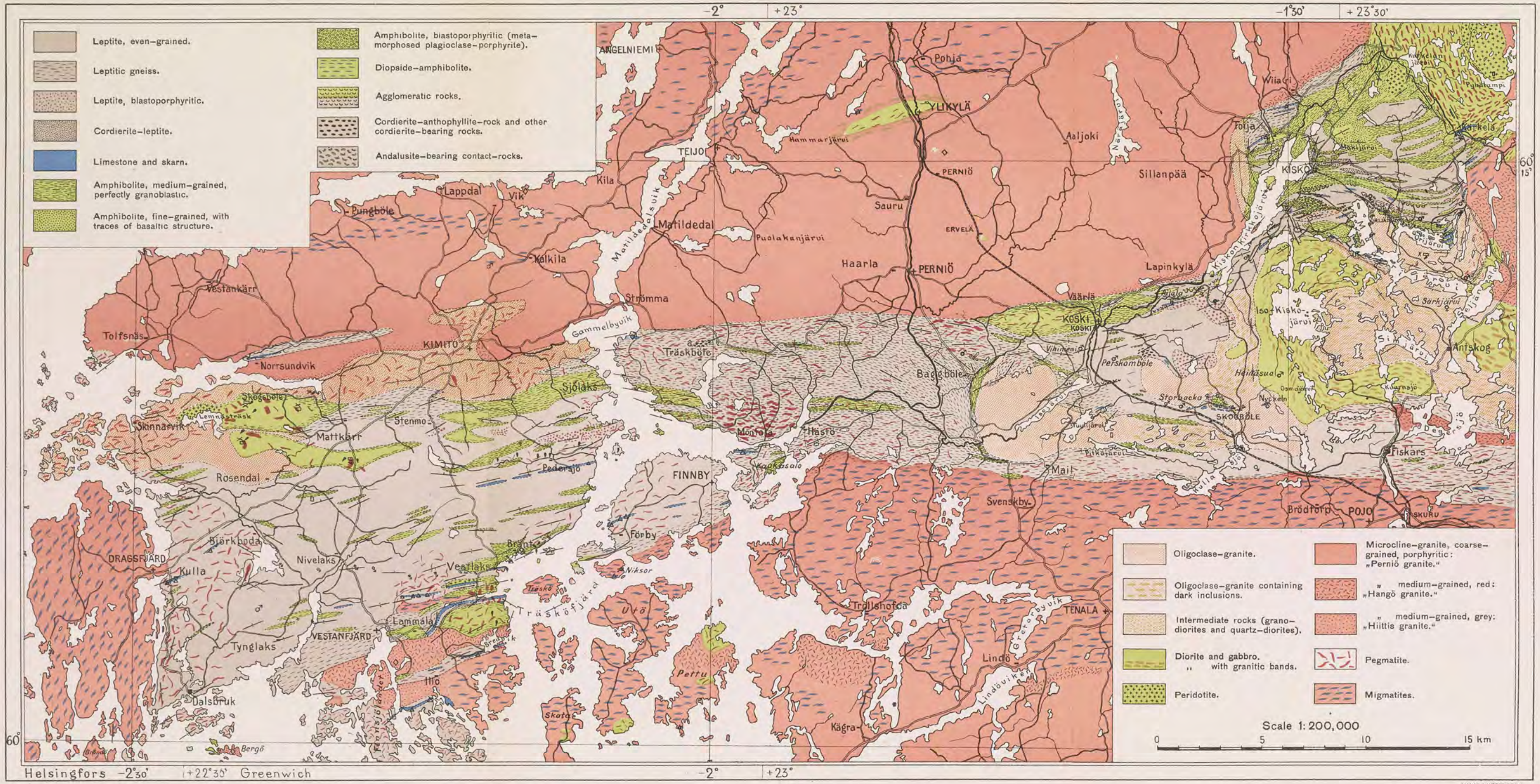


2

Pl. VI.

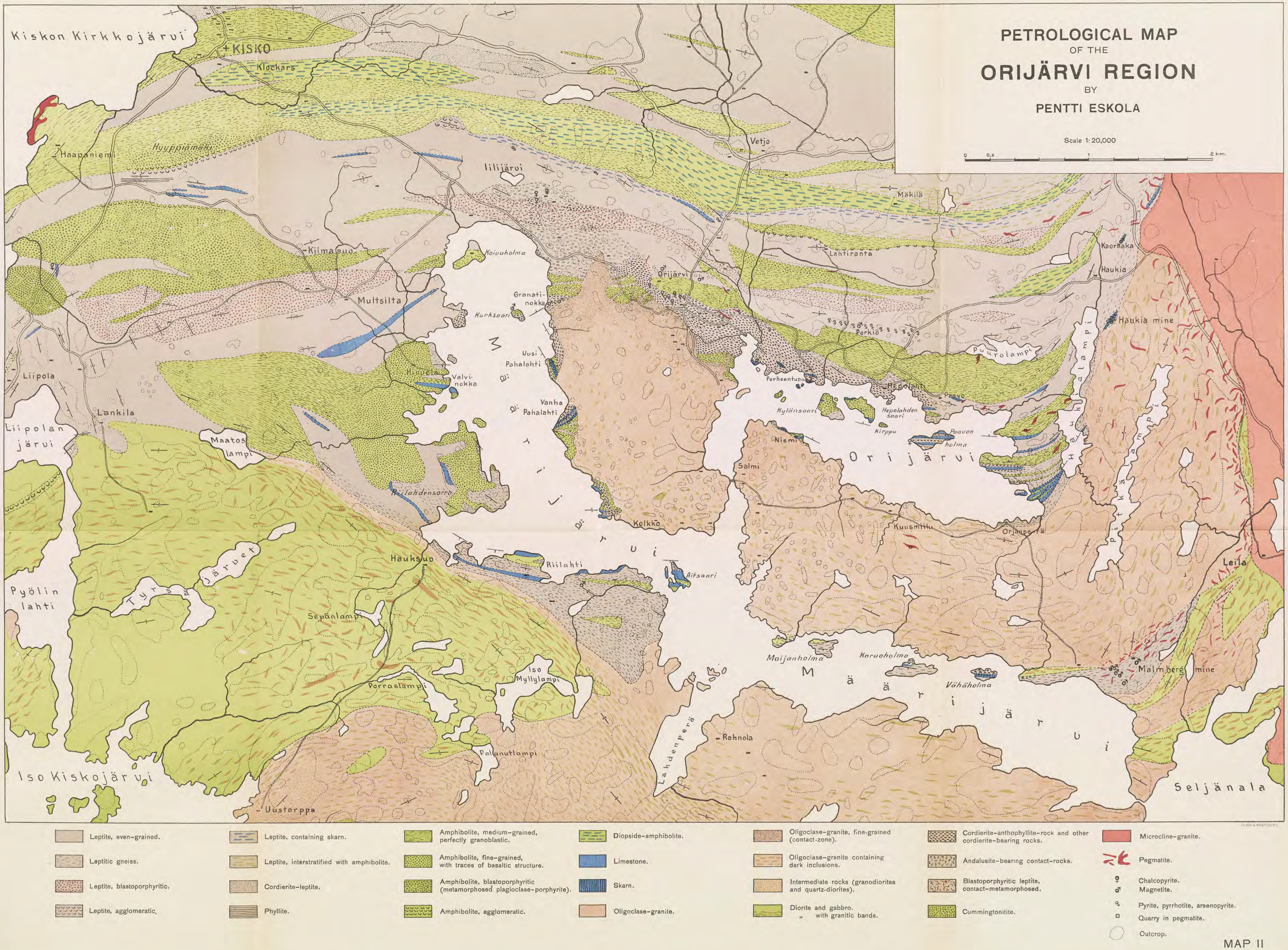
Eskola, Orijärvi Region

PETROLOGICAL MAP OF THE KISKO—KIMITO LEPTITE BELT BY PENTTI ESKOLA



♂ Magnetite. ♀ Chalcopyrite. Blende. Galena. Pyrite, pyrrhotite. — Tantalite, columbite. Beryl. Cassiterite. Tourmaline. — ◊ Quarry in granite. △ Quarry in limestone. ▭ Quarry in pegmatite. ▯ Quarry in quartz-vein.

MAP I


PETROLOGICAL MAP
OF THE
ORIJÄRVI REGION
BY
PENTTI ESKOLA
Scale 1: 20,000
0
0,2
1
2 km.
Kiskon Kirkkojärvi
KISKO
Klockars
Haapaniemi
Hyyppiämäki
Iilijärvi
Vetjo
Mäkilä
Kiimasuo
Multsilta
Koivuholma
Granatinokka
Kurksaari
Orijärvi
Lahtiranta
Kaarnaka
Haukia
Haukia mine
Perkiö
Puurolampi
Liipola
Lankila
Liipolan järvi
Maatoslampi
Hinvela
Valvinokka
Uusi Pahalahti
Vanha Pahalahti
Perheentupa
Hepolahti
Paavo
Kylänsaari
Hepolahden Saari
Kirppu
Paavon holma
Niemi
Orijärvi
Salmi
Riilahdensorro
Kolkko
Kuusmiiu
Orijanpää
Leila
Hauksuo
Riilahti
Aitsaari
Pyölin lahti
Tyrsäjärvet
Sepänlampi
Iso Myllylampi
Porraslampi
Maijanholma
Karuaholma
Vähäholma
Malmberg mine
Määrijärvi
Rahnola
Lahdenperä
Pallanutlampi
Iso Kiskojärvi
Uustorppa
Seljänala
Leptite, even-grained.
Leptitic gneiss.
Leptite, blastoporphyritic.
Leptite, agglomeratic.
Leptite, containing skarn.
Leptite, interstratified with amphibolite.
Cordierite-leptite.
Phyllite.
Amphibolite, medium-grained, perfectly granoblastic.
Amphibolite, fine-grained, with traces of basaltic structure.
Amphibolite, blastoporphyritic (metamorphosed plagioclase-porphyrite).
Amphibolite, agglomeratic.
Diopside-amphibolite.
Limestone.
Skarn.
Oligoclase-granite.
Oligoclase-granite, fine-grained (contact-zone).
Oligoclase-granite containing dark inclusions.
Intermediate rocks (granodiorites and quartz-diorites).
Diorite and gabbro.
" with granitic bands.
Cordierite-anthophyllite-rock and other cordierite-bearing rocks.
Andalusite-bearing contact-rocks.
Blastoporphyritic leptite, contact-metamorphosed.
Cummingtonitite.
Microcline-granite.
Pegmatite.
Chalcopyrite.
Magnetite.
Pyrite, pyrrhotite, arsenopyrite.
Quarry in pegmatite.
Outcrop.

MAP II

N:o 20. Zur geologischen Geschichte des Kilpisjärvi-Sees in Lappland, von V. Tanner. Mit einer Karte und zwei Tafeln. April 1907 ... 1:—
N:o 21. Studier öfver kvartärsystemet i Fennoskandias nordliga delar. II. Nya bidrag till frågan om Finmarkens glaciation och nivåförändringar, af V. Tanner. Med 6 taflor. Résumé en français: Études sur le système quaternaire dans les parties septentrionales de la Fenno-Scandia. II. Nouvelles recherches sur la glaciation et les changements de niveau du Finmark. Juin 1907 ... 3:50
N:o 22. Granitporphyr von Östersundom, von L. H. Borgström. Mit 3 Figuren im Text und einer Tafel. Juni 1907 ... 1:—
N:o 23. Om granit och gneis, deras uppkomst, uppträdande och utbredning inom urberget i Fennoskandia, af J. J. Sederholm. Med 8 taflor, en planteckning, en geologisk öfversiktskarta öfver Fennoskandia och 11 figurer i texten. English Summary of the Contents: On Granite and Gneiss, their Origin, Relations and Occurrence in the Pre-Cambrian Complex of Fenno-Scandia. With 8 plates, a coloured plan, a geological sketch-map of Fenno-Scandia and 11 figures. Juli 1907 ... 3:—
N:o 24. Les roches préquaternaires de la Fenno-Scandia, par J. J. Sederholm. Avec 20 figures dans le texte et une carte. Juillet 1910 ... 1:50
N:o 25. Über eine Gangformation von fossilienführendem Sandstein auf der Halbinsel Långbergsöda-Öjen im Kirchspiel Saltvik, Åland-Inseln. von V. Tanner. Mit 2 Tafeln und 5 Fig. im Text. Mai 1911 ... 1:25
N:o 26. Bestimmung der Alkalien in Silikaten durch Aufschliessen mittelst Chlorkalzium, von Eero Mäkinen. Mai 1911 ... —:50
N:o 27. Esquisse hypsométrique de la Finlande, par J. J. Sederholm. Avec une carte et 5 figures dans le texte. Juillet 1911 ... 1:50
N:o 28. Les roches préquaternaires de la Finlande, par J. J. Sederholm. Avec une carte. Juillet 1911 ... 1:50
N:o 29. Les dépôts quaternaires de la Finlande, par J. J. Sederholm. Avec une carte et 5 figures dans le texte. Juillet 1911 ... 1:50
N:o 30. Sur la géologie quaternaire et la géomorphologie de la Fenno-Scandia, par J. J. Sederholm. Avec 13 figures dans le texte et 6 cartes. Juillet 1911 ... 1:50
N:o 31. Undersökning af porfyrblock från sydvästra Finlands glaciala aflagringar, af H. Hausen. Mit deutschem Referat. Mars 1912 ... 1:—
N:o 32. Studier öfver de sydfinska ledblockens spridning i Ryssland, jämte en öfversikt af is-recessionens förlopp i Ostbaltikum. Preliminärt meddelande med tvenne kartor af H. Hausen. Mit deutschem Referat. Mars 1912 ... 1:—
N:o 33. Kvartära nivåförändringar i östra Finland, af W. W. Wilkman. Med 9 figurer i texten. Deutsches Referat. April 1912 ... 1:—
N:o 34. Der Meteorit von St. Michel, von L. H. Borgström. Mit 3 Tafeln und 1 Fig. im Text. August 1912 ... 1:50
N:o 35. Die Granitpegmatite von Tammela in Finnland, von Eero Mäkinen. Mit 23 Figuren und 13 Tabellen im Text ... 1:50
N:o 36. On Phenomena of Solution in Finnish Limestones and on Sandstone filling Cavities, by Pentti Eskola. With 15 Figures in the Text ... 1:50
N:o 37. Weitere Mitteilungen über Bruchspalten mit besonderer Beziehung zur Geomorphologie von Fennoskandia, von J. J. Sederholm. Mit einer Tafel und 27 Figuren im Text ... 1:50
N:o 38. Lapplands istidsgeologi af V. Tanner, en train de paraître ...
N:o 39. Der gemischte Gang von Tuutijärvi im nördlichen Finnland, von Victor Hackman. Mit 4 Tabellen und 9 Figuren im Text. Mai 1914 ... 1:50
N:o 40. On the Petrology of the Orijärvi region in Southwestern Finland, by Pentti Eskola ... 4:—
N:o 41. Die Skapolithlagerstätte von Laurinkari, von L. H. Borgström ... 1:50
N:o 42. Über Camptonitgänge im mittleren Finnland, von Victor Hackman. Aug. 1914. 1:50